



Geant4: A Simulation toolkit

O. Stézowski and I. Companis



With many thanks to the Geant4 community !!!!

The roadmap of the week

Why?

What is It?



Geant 4

The roadmap of the week

Why?

This lecture, 1h30

What is It?



Geant 4

The roadmap of the week

Why?

This lecture, 1h30

What is It?

How
4 workshops
13h30

Geant 4



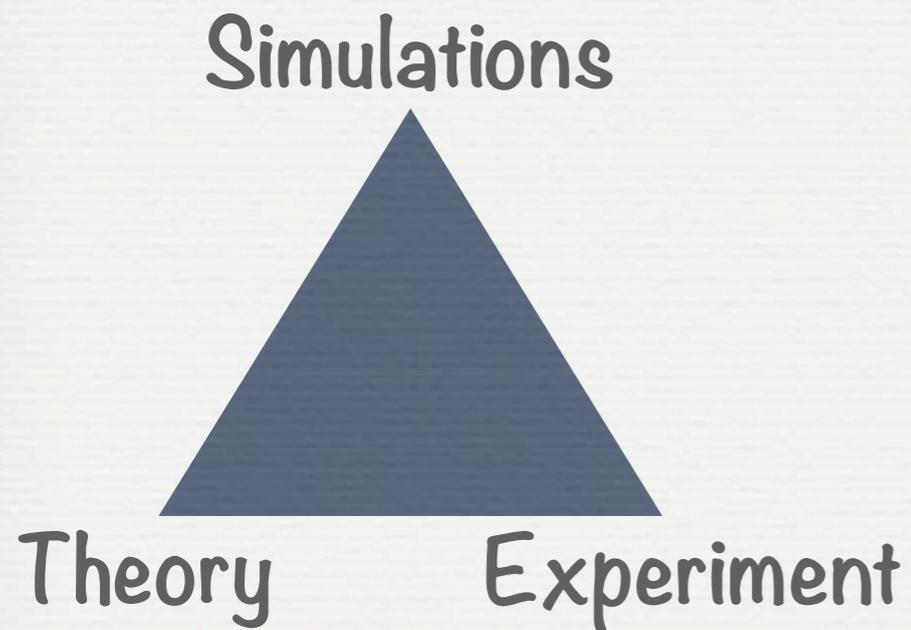


A personal, general view

More practical reasons

Why?

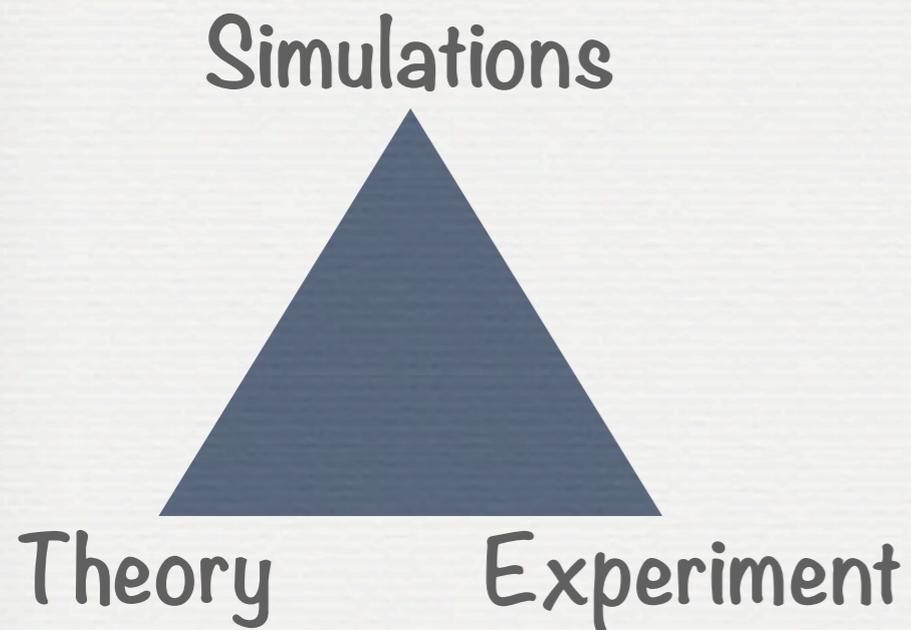
Why simulations ..



A guy, a seminar, somewhere:
place of simulations in physics

Why?

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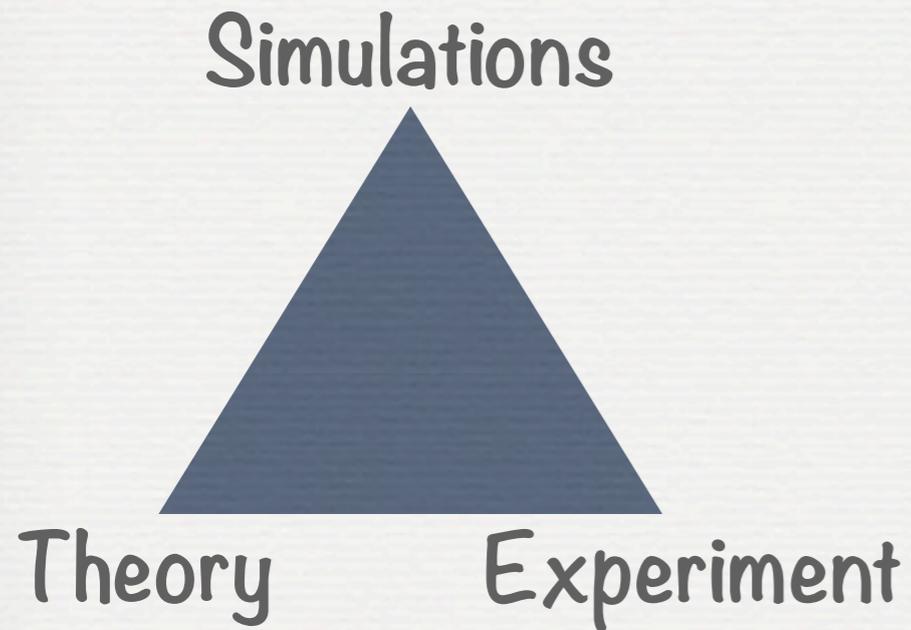


common to all of us

physicist

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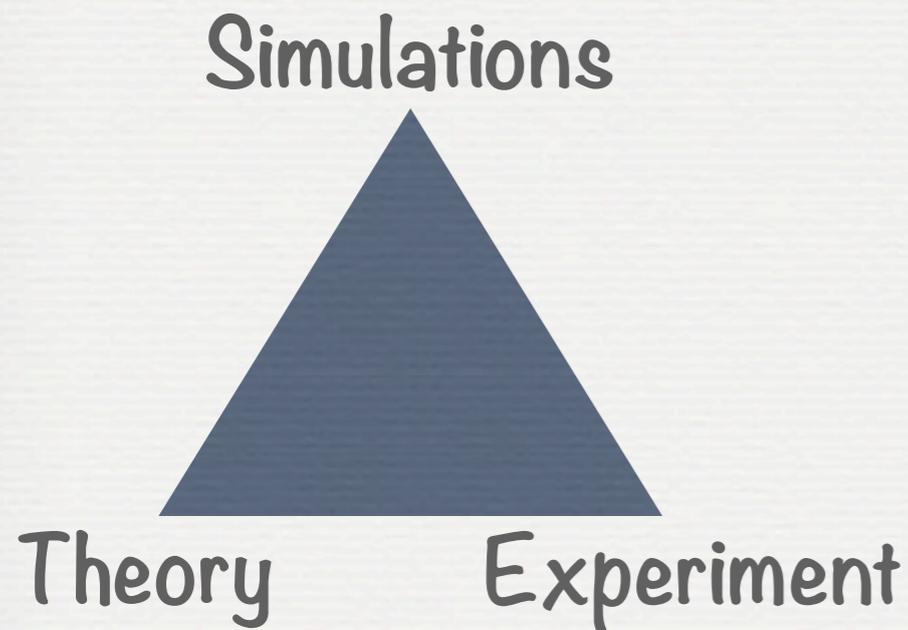
what we like to play with

common to all of us

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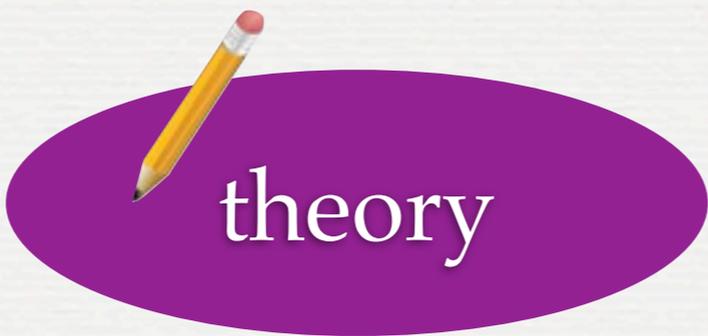
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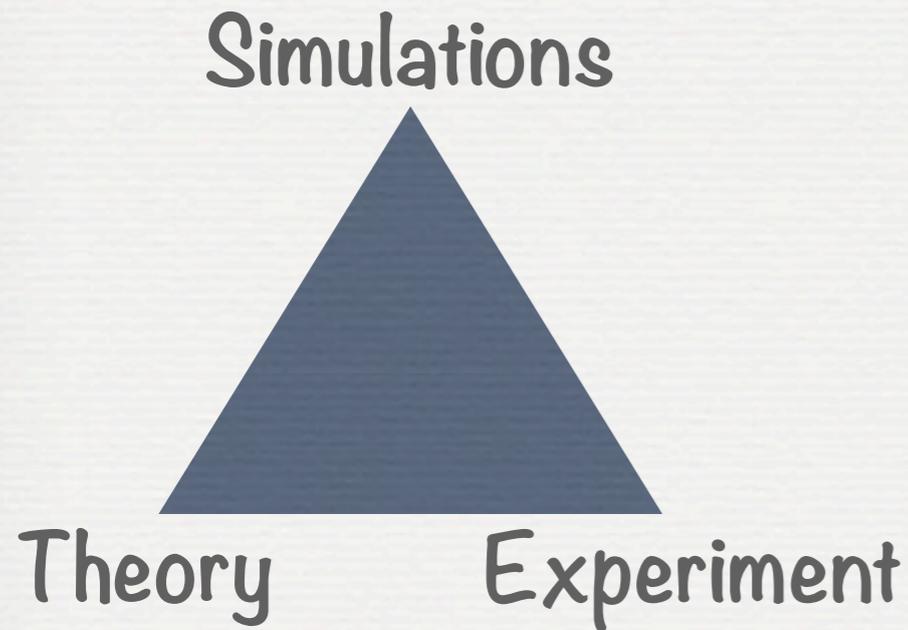


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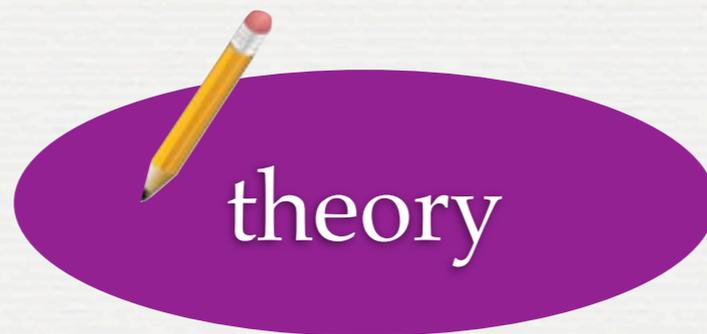
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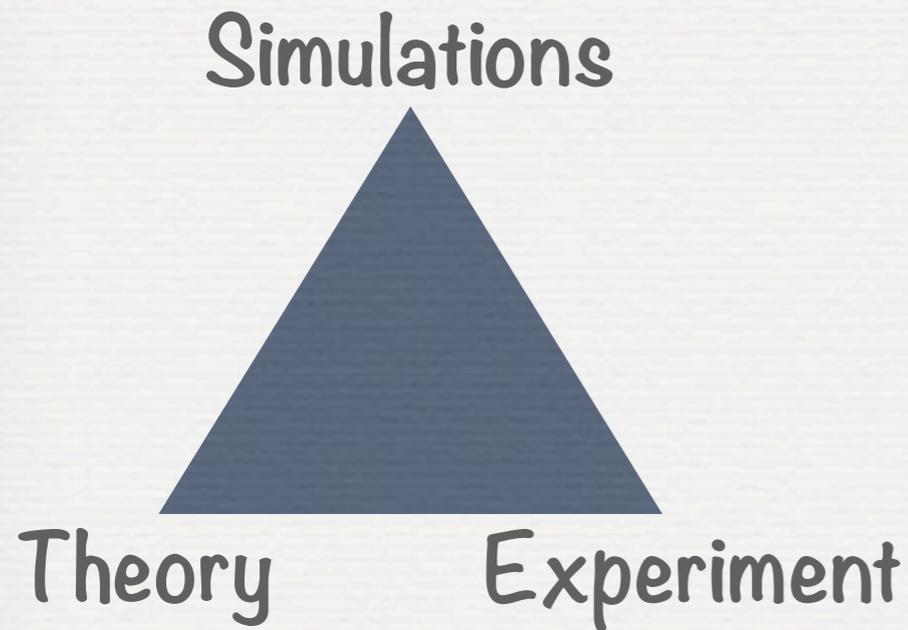


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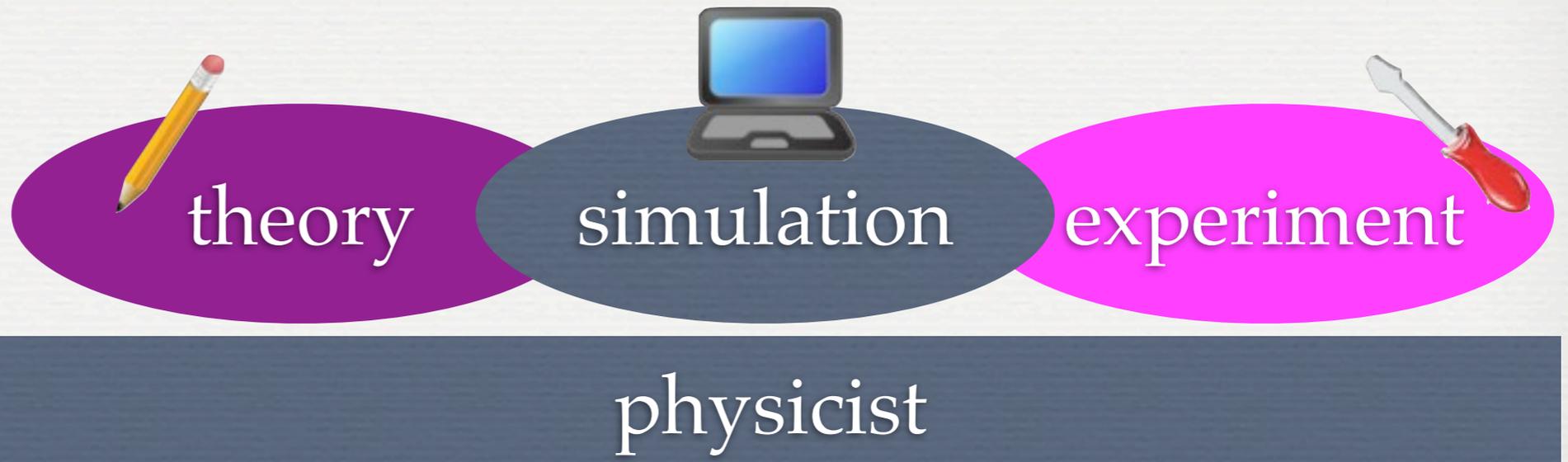
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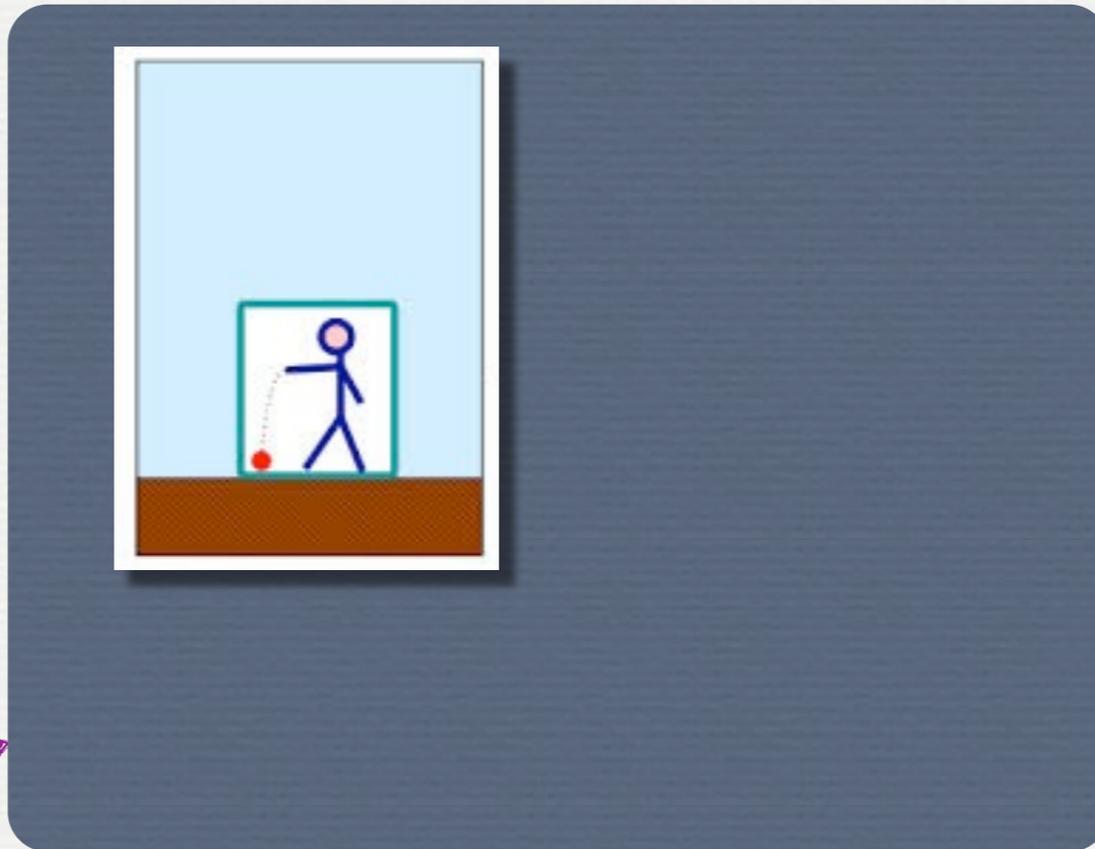
what we like to play with

common to all of us



Why?

Why simulations ...



what we like to play with

theory

simulation

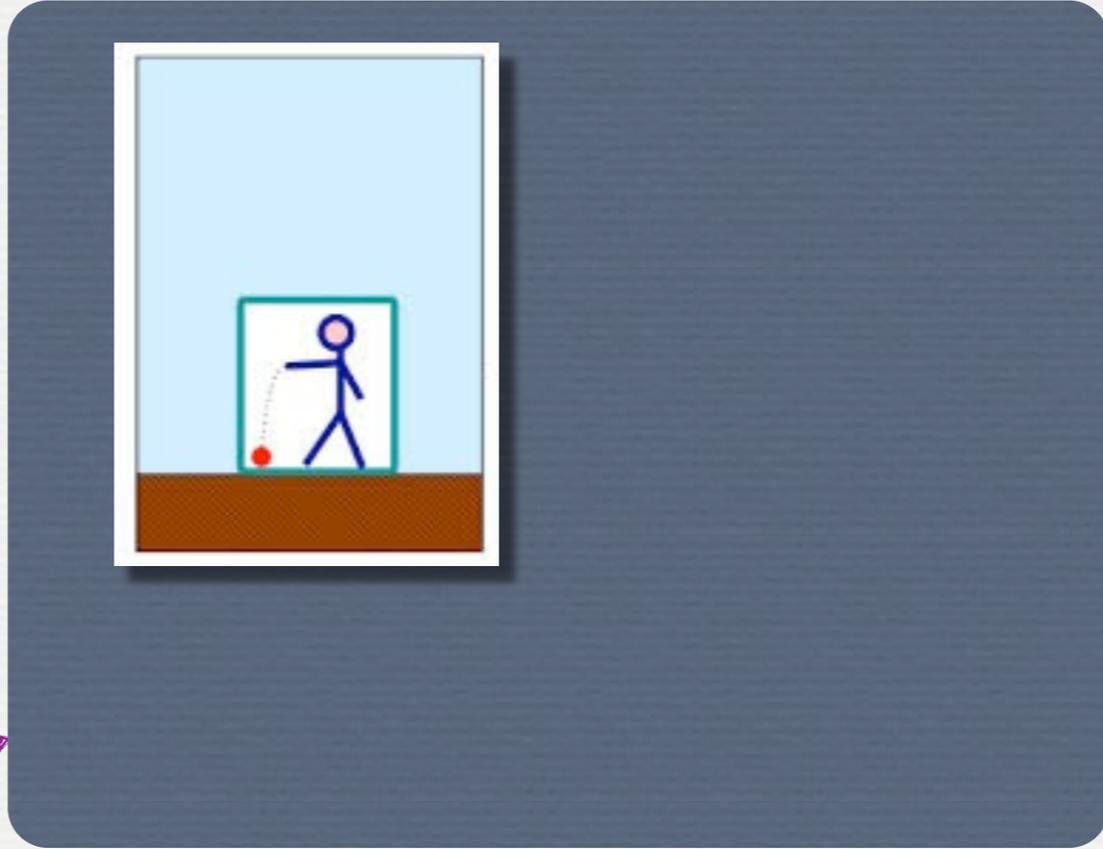
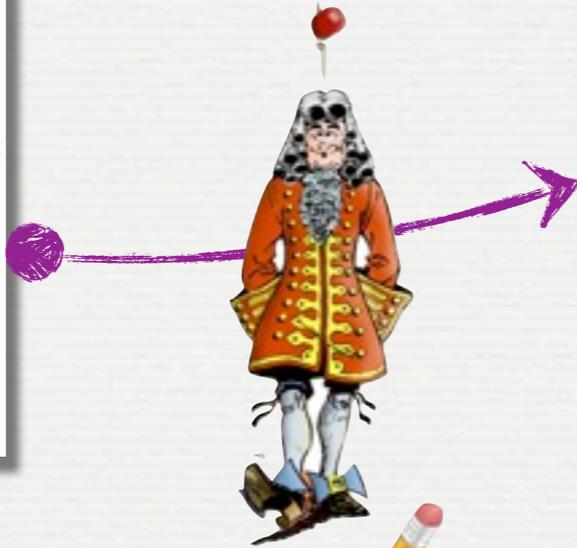
experiment

common to all of us

physicist

Why?

Why simulations ...



what we like to play with

common to all of us

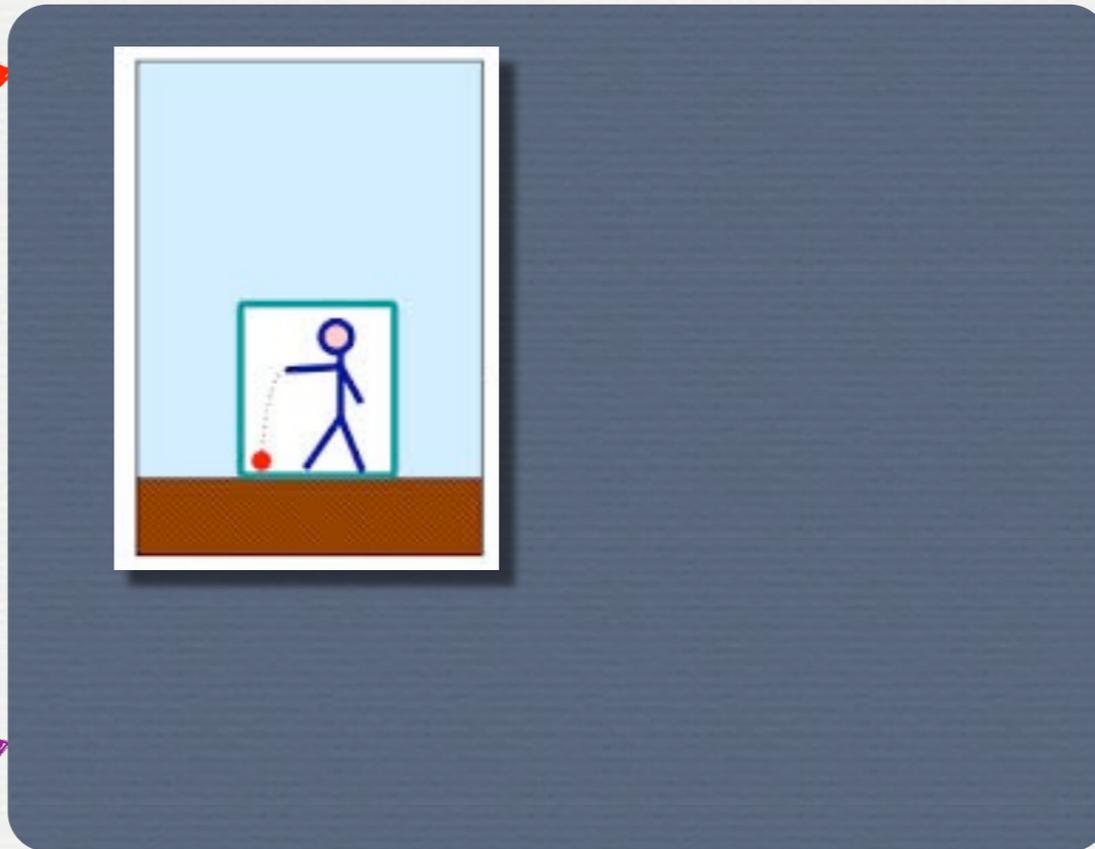


physicist

Why?

Why simulations ...

What if I change ...



what we like to play with

common to all of us

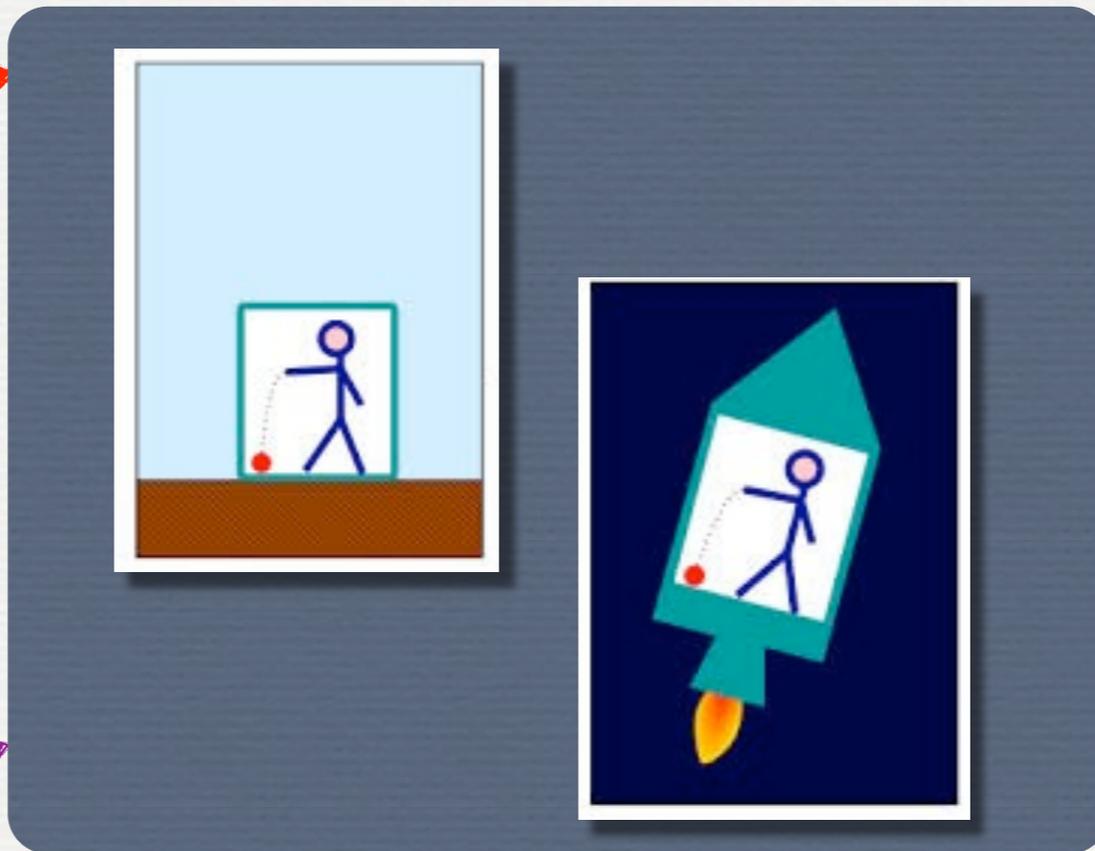


physicist

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what we like to play with

theory

simulation

experiment

common to all of us

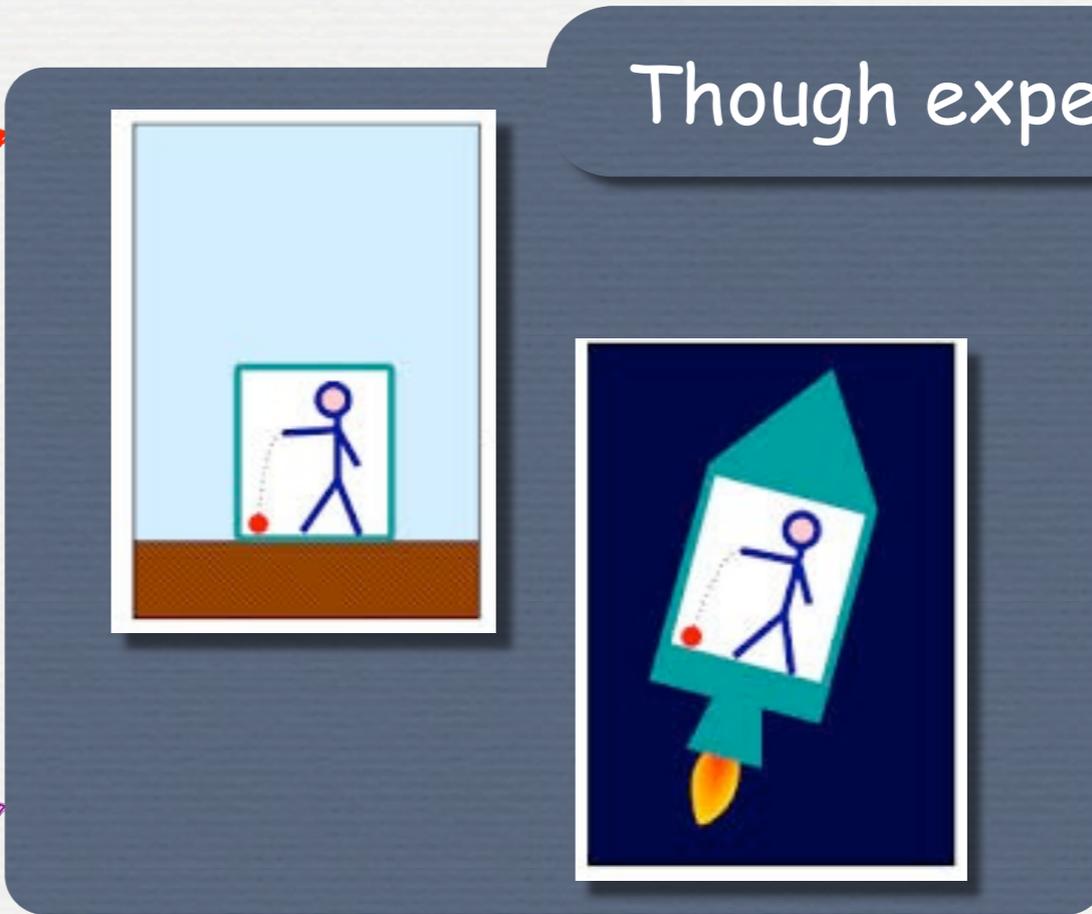
physicist

Why?

Why simulations ...

What if I change ...

Though experiment !!



what we like to play with

theory

simulation

experiment

common to all of us

physicist

Why?

Why simulations ...



It allows to be:

- ▶ less expensive
- ▶ quicker ... **well may be not** ...
- ▶ less dangerous
- ▶ ...



It allows to control everything:

- ▶ cause → effect relationship
- ▶ step by step, more and more complexity
- ▶ step by step, more and more realism
- ▶ ...

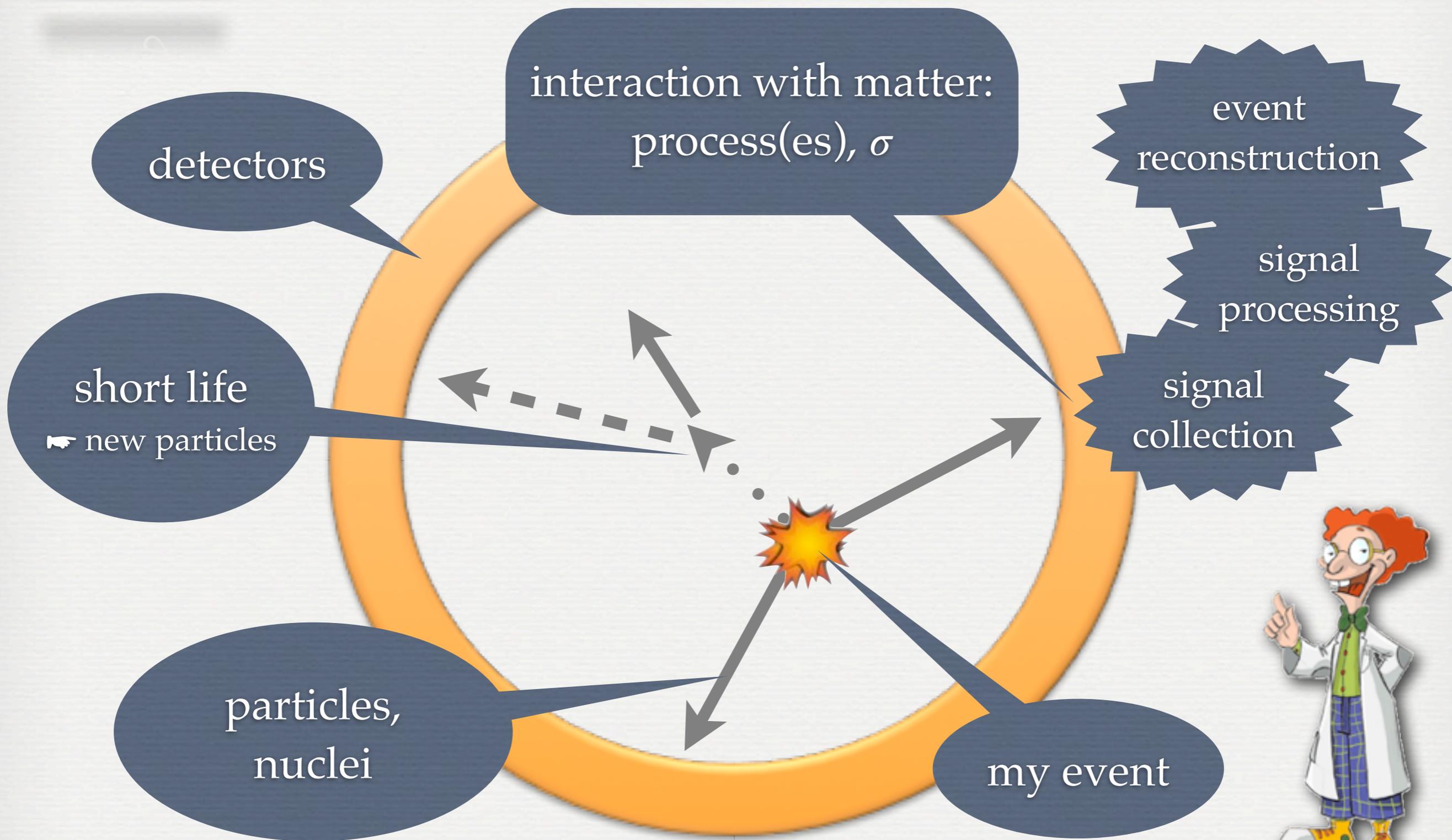


A personal, general view

More practical reasons

Why?

In our 'field', particles ...



Why?

Why simulations for us ...

- Detectors are:
 - ▶ more and more complex / precise
 - ▶ expansive ...
 - ▶ long time for R&D phase
 - ▶ long time to have them working well
- Events to be treated are:
 - ▶ complex
 - ▶ various
 - ▶ rare for the most interesting ones (background!)

Why?

Why simulations for us ...

« before » the detector is built

- to study new concepts
- establish raw performances*
- to study different triggers
- to optimize reconstructions
- to set experimental limits
- ...

➡ tools for R&D

* acceptance, response function ...

« during » the life of the detector

- to optimize experimental setup
signal ↗, background ↘, selection
- to understand problems in data
lost of efficiency, resolution
- to improve signal/background
- to improve physics models
- ...

➡ to help for data analysis

➡ to understand physics

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What is It?

Some general statements

Monte Carlo into the *game*

Geant4 some vocabulary

The Geant4 machine

What is It? Simulation landscape, some tools

● GEANT4 : GEometry ANd Tracking

➔ <http://geant4.cern.ch/>

● FLUKA : FLUktuierende KAskade

alternative to Geant4

➔ <http://www.fluka.org/fluka.php>

● MCNP(X) : Monte-Carlo N-Particle

More Nuclear Physics (Manhattan's project)

➔ <http://mcnp.lanl.gov/>

Geant 4



FLUKA



mcnp



What is It? Simulation landscape, many tools

EGS4, EGS5, EGSnrc

Geant3, Geant4

MARS

MCNP, MCNPX, A3MCNP, MCNP-DSP, MCNP4B

MVP, MVP-BURN

Penelope

Peregrine

Tripoli-3, Tripoli-3 A, Tripoli

DPM

EA-MC

FLUKA

GEM

HERMES

LAHET

MCBEND

MCU

MF3D

NMTC

MONK

MORSE

RTS&T-2000

SCALE

TRAX

VMC++

- pythia, herwig, hijing in particles ϕ
- evapor, fresco, empire in nuclear ϕ
- ...

physics generators

user's doc

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user's forum

Geant 4

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Search Geant4

Geant4 is a toolkit for the simulation of the passage of particles through matter. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science. The two main reference papers for Geant4 are published in *Nuclear Instruments and Methods in Physics Research A* 501 (2003) 250-303, and *IEEE Transactions on Nuclear Science* 53 No. 1 (2006) 270-278.

Applications

A sampling of applications, technology transfer and other uses of Geant4

User Support

Getting started, guides and information for users and developers

Results & Publications

Validation of Geant4, results from experiments and publications

Collaboration

Who we are: collaborating institutions, members, organization and legal information

News

- 28 June 2013 - Release 10.0 BETA is available from the [Beta download](#) area.
- 24 May 2013 - Patch-02 to release 9.6 is available from the [download](#) area.
- 18 March 2013 - [2013 planned developments](#).
- 30 October 2012 - Patch-02 to release 9.5 is available from the [archive download](#) area.

Events

- [Geant4 2013 International User Conference on Medicine and Biology applications](#), Bordeaux (F)
- [Past events](#)

news system
think your code as living 'object' !

Upgrade if needed
good practices in practical sessions

Major.Minor.[Patch]or[Beta]

Minor

- should not break your code
- new features / slightly different results

Major

- may (is likely to) break you code
- see release notes to help - warnings at running time

Patch: only bugs, no new features

Beta: to help the G4 community to develop ...

user's doc

Geant 4

[Home](#) > [User Support](#)

User Support

- [Getting started](#)
- [Training courses and materials](#)
- [Source code](#)
 - [Download page](#)
 - [LXR code browser -or- draft doxygen documentation](#)
- [Frequently Asked Questions \(FAQ\)](#)
- [Bug reports and fixes](#)
- [User requirements tracker](#)
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 - [Introduction to Geant4](#)
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- [Examples](#)
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 - [Process/model catalog](#)
 - [General particle source](#)
- [Contact Coordinators & Contac](#)

Geant 4

Geant4 Cross Reference

Search Menu:

[geant4/](#) Browse the source code tree.

[File Name Search](#)

Search for files by name (case sensitive).

[Full-Text Search](#)

Search through all the text.

[Identifier Search](#)

Find a class, method, variable, etc.

Geant4 User's Guide for Application

Geant4 Collaboration

Version: geant4 9.6.0

30th November, 2012

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- [1.2. How to use this manual](#)

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[2.2. How to Define a Detector Geometry](#)

- [2.2.1. Basic Concepts](#)
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- [2.2.5. Place a Volume](#)
- [2.2.6. Create a Physical Volume](#)
- [2.2.7. Coordinate Systems and Rotations](#)

[2.3. How to Specify Materials in the Detector](#)

Hi,

This is an interactive viewing and searching facility for the Geant4 source code.

It offers:

Source-tree browsing and file name search to easily find source files and navigate through the source directories.

Full-text indexing for fast retrieval of source files containing a given word or pattern.

Identifier cross-reference for fully hyperlinked source code. The names of classes, methods, and data can be clicked on to find the source files where they are defined and used.

The full-text indexing and retrieval are implemented using [Glimpse](#), so all the capabilities of Glimpse are available. Please see [Glimpse document](#) for details. Note that glimpse syntax is available for text and identifier searches. For file name search, please use regular expression.

Note

All source files are rendered into HTML. Do not attempt to download the Geant4 source code from this site!

Links

pdf also

organized in categories

user's forum

The screenshot shows the 'GEANT4 at hypernews.slac.stanford.edu Forum List by Category' page. The page has a blue header with the 'Geant 4' logo and navigation links. The main content is organized into several categories, each with a list of sub-links. A grey callout bubble points to the 'Geometry' link under the 'Experimental Setup' category.

GEANT4 at hypernews.slac.stanford.edu Forum List by Category Not Logged In ([login](#))

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Category: Applications
[Educational Applications](#) [Industrial instruments](#) [Medical Applications](#) [Space Applications](#)

Category: Control of runs, events, tracks, particles
[Event and Track Management](#) [Multithreading](#) [Particles](#) [Run Management](#)

Category: Experimental Setup
[Biasing and Scoring](#) [Fields: Magnetic and Otherwise](#) [Geometry](#) [Hits, Digitization and Pileup](#)

Category: General matters
[Documentation and Examples](#) [HyperNews System Announcements](#) [Hypernews Testing](#) [Installation and Configuration](#)
[User Requirements](#)

Category: Interfaces
[\(Graphical\) User Interfaces](#) [Analysis](#) [Persistency](#) [Visualization](#)

Category: Physics
[Biasing and Scoring](#) [Electromagnetic Processes](#) [Fast Simulation, Transportation & Others](#) [Hadronic Processes](#)
[Physics List](#) [Processes Involving Optical Photons](#)

This site runs [SLAC HyperNews](#) version 1.11-slac-98, derived from the original [HyperNews](#)

<http://hypernews.slac.stanford.edu/HyperNews/geant4/cindex>

toolkit: do not hesitate to spend time in looking if things already exists !
- features / bugs known
- elegant solutions already found



Overview

Members

Activities

News

Tutorials and teachings

Conferences,
workshops and
meetings

Geant4 Virtual Machine

Jobs

Useful links

Publications

The Geant4-DNA project

The BioRad project

BioRad Collaboration

The BioRad II project

BioRad II Collaboration

Visualization & Qt

Search

On this website

On the whole CNRS Web



 News front page

Geant4 9.6+P02 Virtual Machine now available for download

Download the software suite from the Geant4 for VMware section.

- Friday 31 May 2013 - [Read](#) 

Geant4 2013 User Conference at the Physics-Medicine-Biology frontier

The Geant4 2013 International User Conference to be held in Bordeaux, France, from October 7th till October 11th, 2013 is announced. Registration is open. All details are available from (...)

- Monday 11 March 2013 - [Read](#) 

Geant4 9.6+P01 Virtual Machine now available for download

Download the software suite from the Geant4 for VMware section.

- Tuesday 12 February 2013 - [Read](#) 

Geant4 9.6 Virtual Machine now available for download

Download the software suite from the Geant4 for VMware section.

- Thursday 13 December 2012 - [Read](#) 

Two post-doctoral positions available at CENBG

For more information , please consult the Jobs section.

- Wednesday 5 December 2012 - [Read](#) 

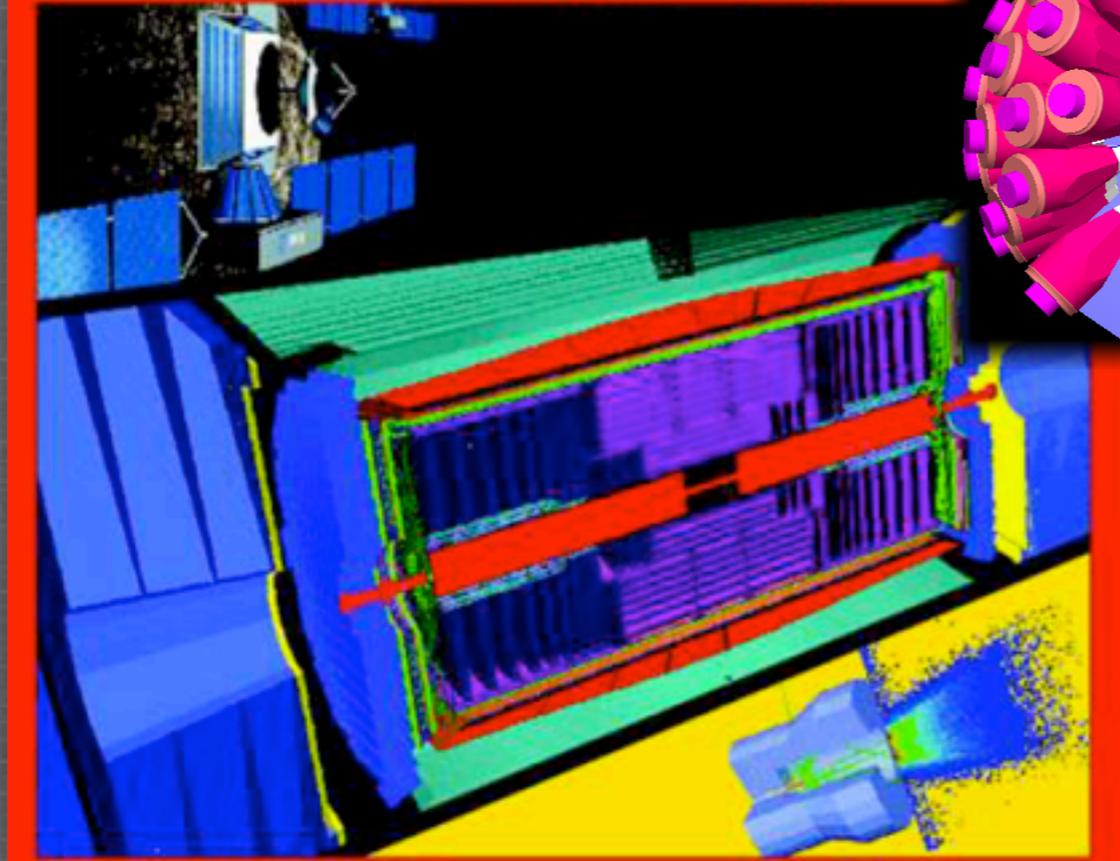
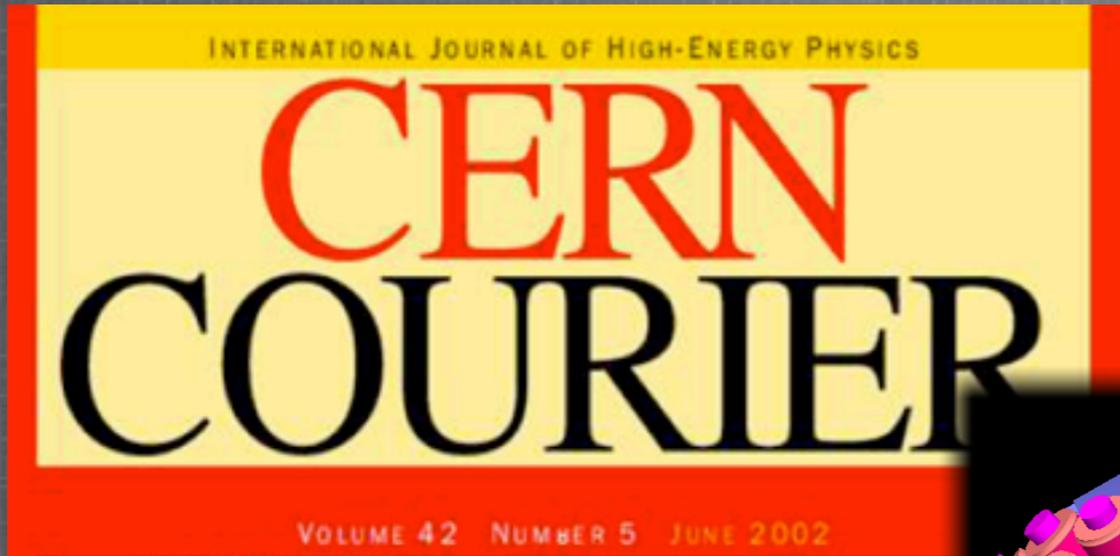
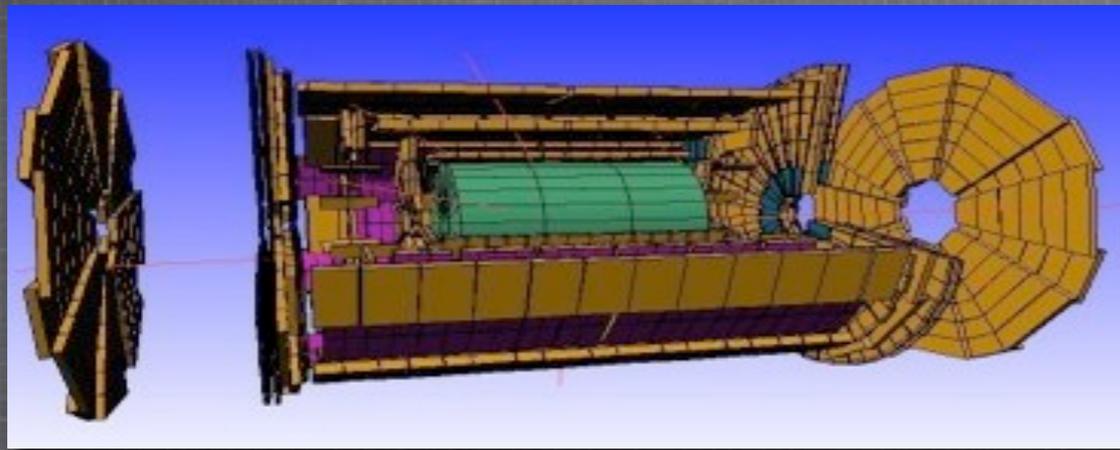
Geant4 workshop & tutorial in Wollongong U., Australia

See more at this link

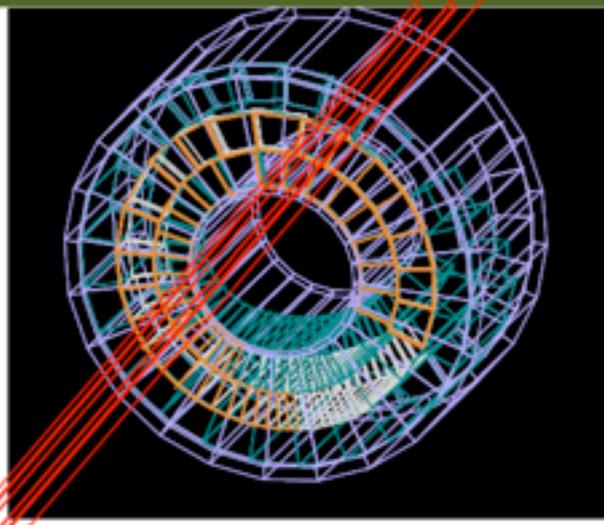
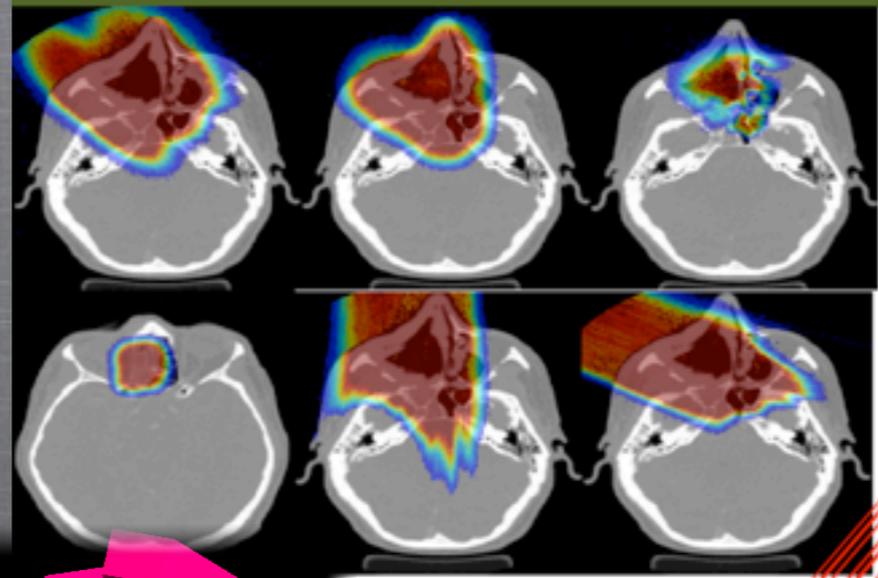
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<http://geant4.in2p3.fr>

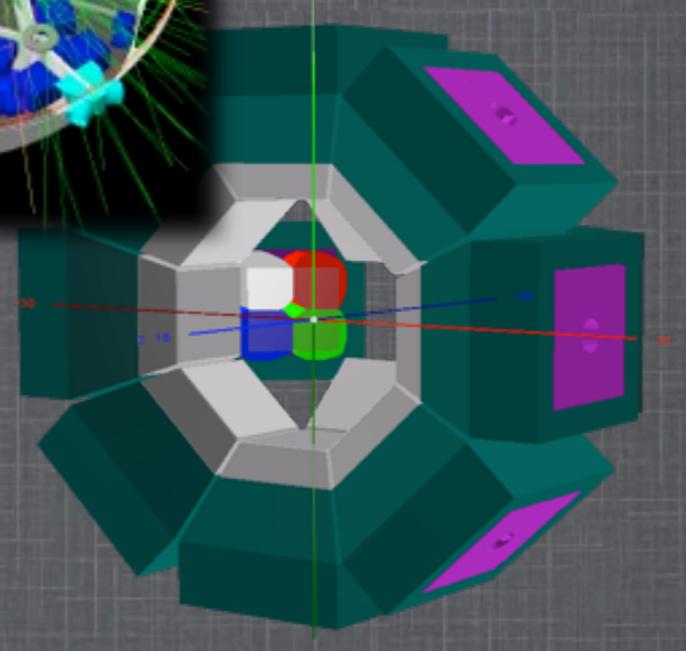
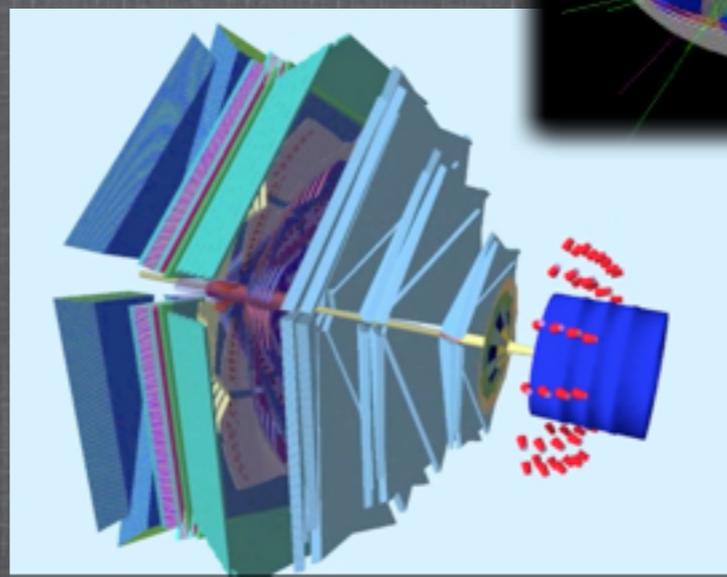
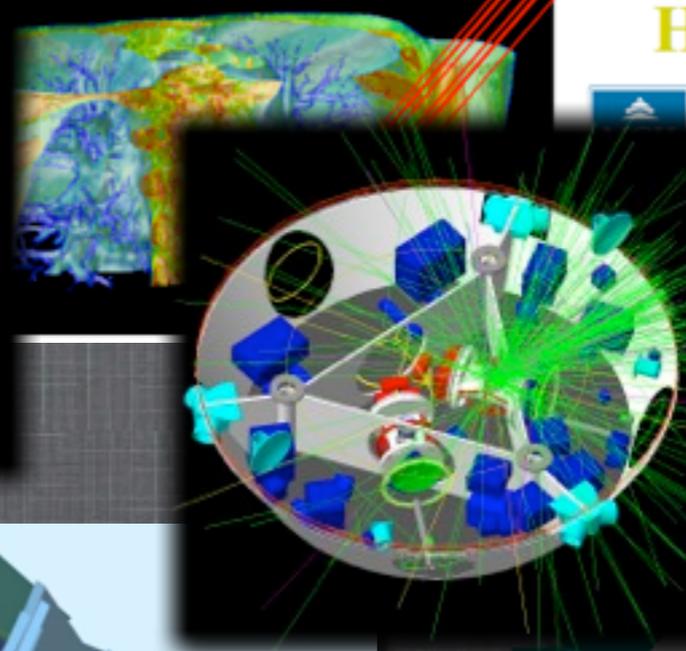
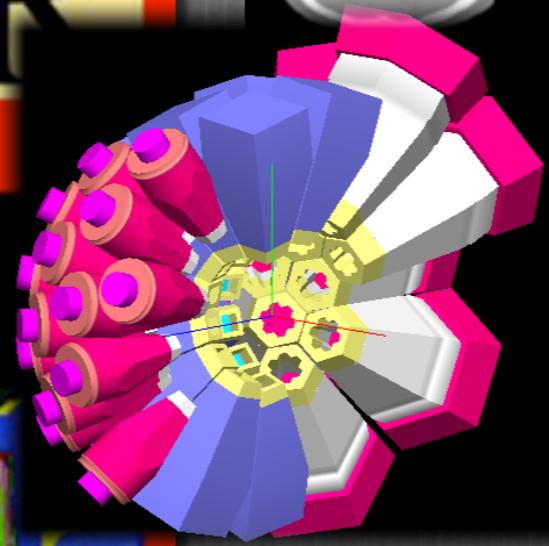
GEANT4 based proton dose calculation in a clinical environment: technical aspects, strategies and challenges



Simulation for physics, space and medicine



Harald Paganetti
MASSACHUSETTS
GENERAL HOSPITAL
HARVARD
MEDICAL SCHOOL





Some general statements

Monte Carlo into the *game*

Geant4 some vocabulary

The Geant4 machine

What is It?

Monte Carlo method ...

- At least one uniform generator required [0,1[

↳ the random engine produce pseudo-random numbers ...



ROOT

<i>TRandom</i>	10^9	34 ns	linear congruential $X_{n+1} = (aX_n + C) \% m$
<i>TRandom1</i>	10^{171}	242 ns	RANLUX
<i>TRandom2</i>	10^{26}	37 ns	Tausworthe de l'Ecuyer
<i>TRandom3</i>	10^{6000}	45 ns	Mersenne Twister

+ initialization: **seed (reproducibility) !**

↳ according to your needs. Do not run twice with same seed to add data ...

- With this one, more complex ones can be built >>>>



<http://root.cern.ch>

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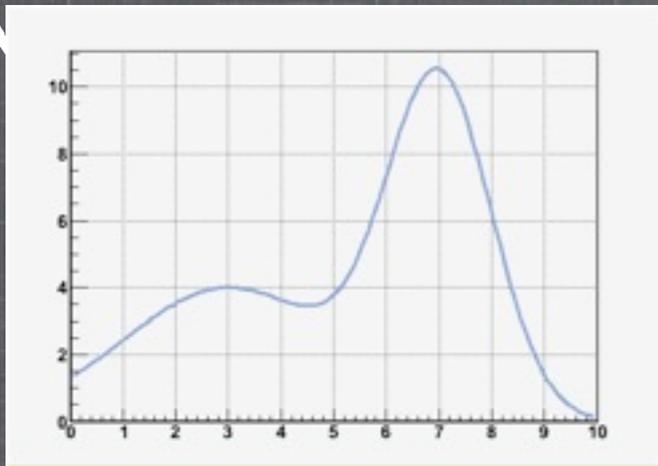
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Monte Carlo method ...

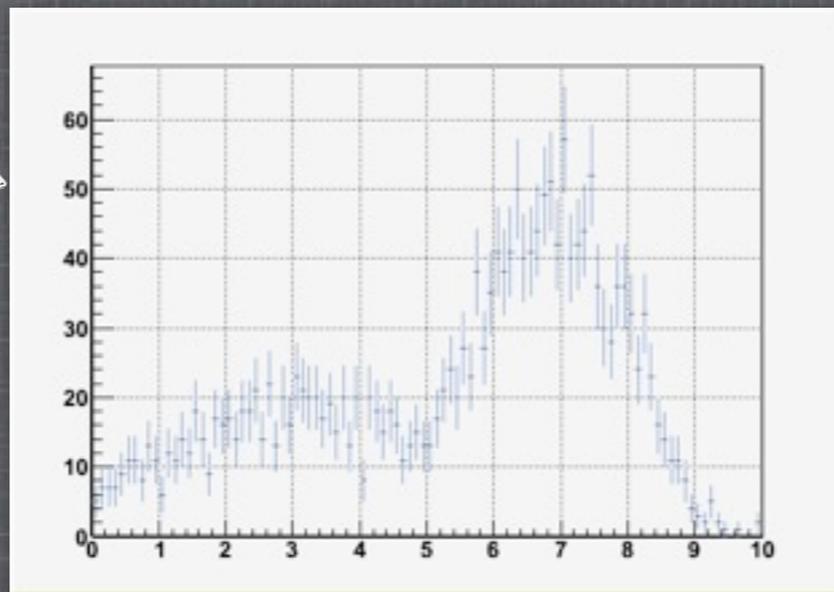
- if $f(x)$ is a probability density function -

Inverse Method

x uniform in $[0,1[\Rightarrow F^{-1}(x)$ is 'f(x) distributed'
 $F^{-1} \leftarrow F$ cumulative distribution function

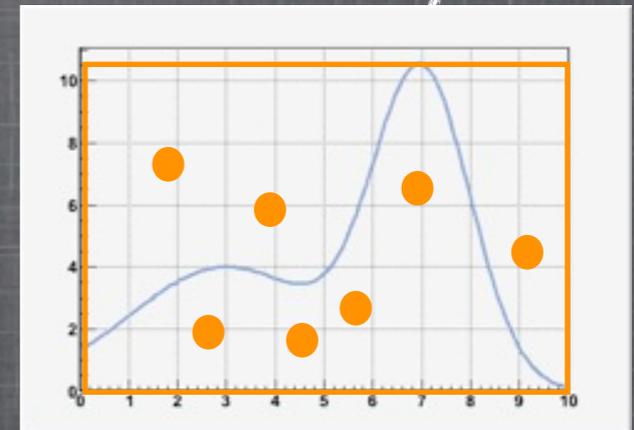


$$F(x) = \frac{\int^x f(u) du}{\int f(u) du}$$



Accept - Reject Method

(x_i, y_i) uniform in \square



accept x_i if $y_i < f(x_i)$
 $\rightarrow x_i$ 'f(x) distributed'!

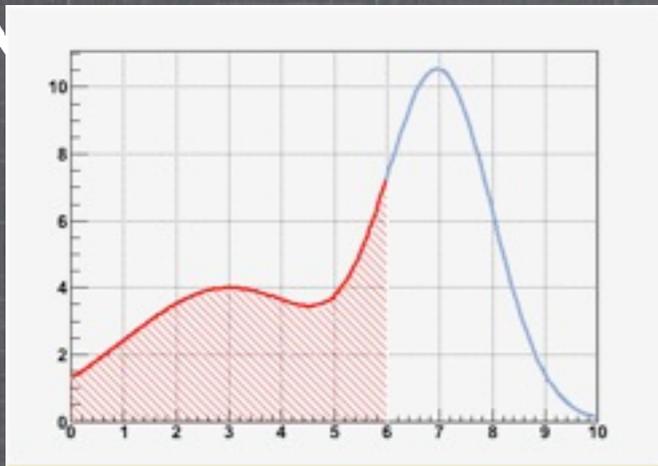
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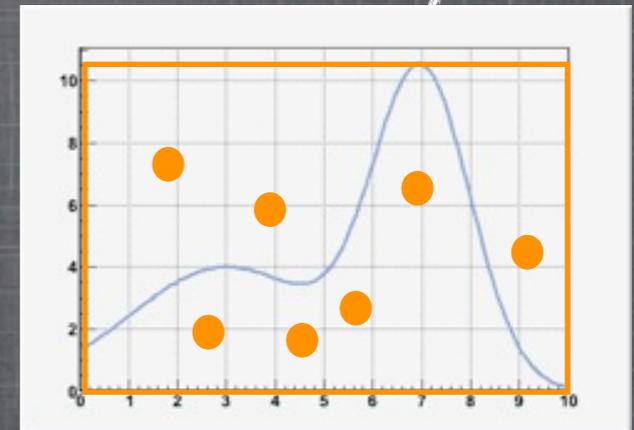
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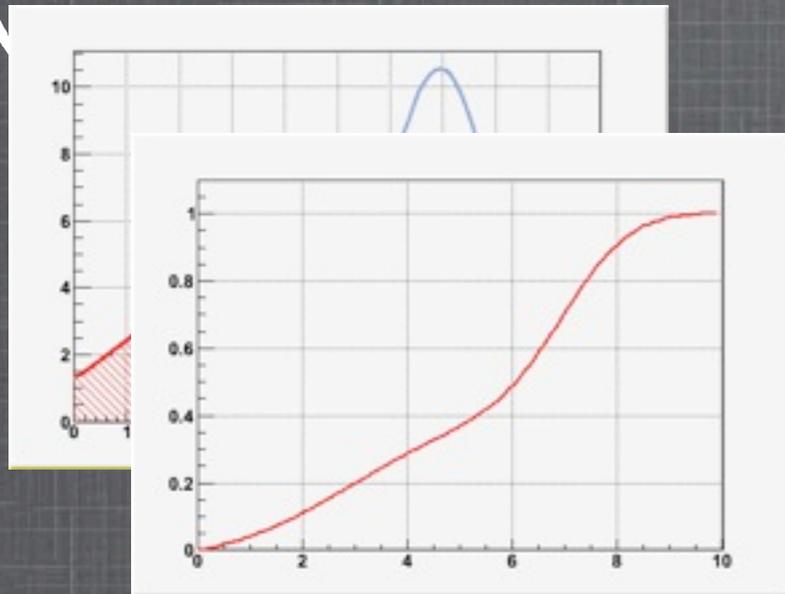
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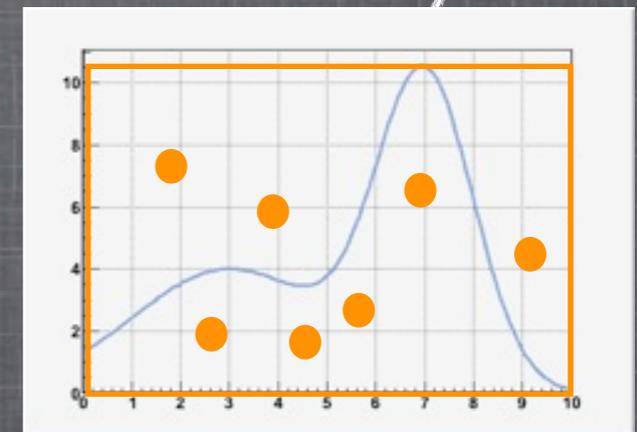


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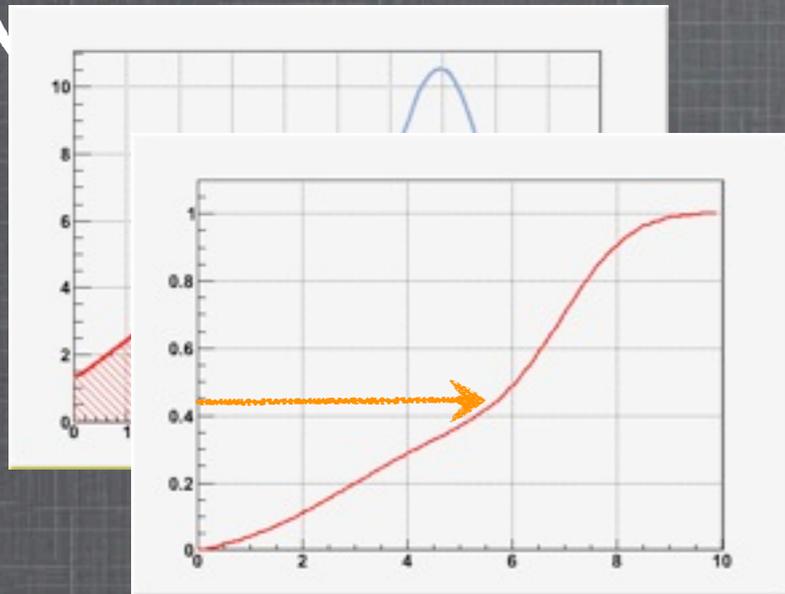
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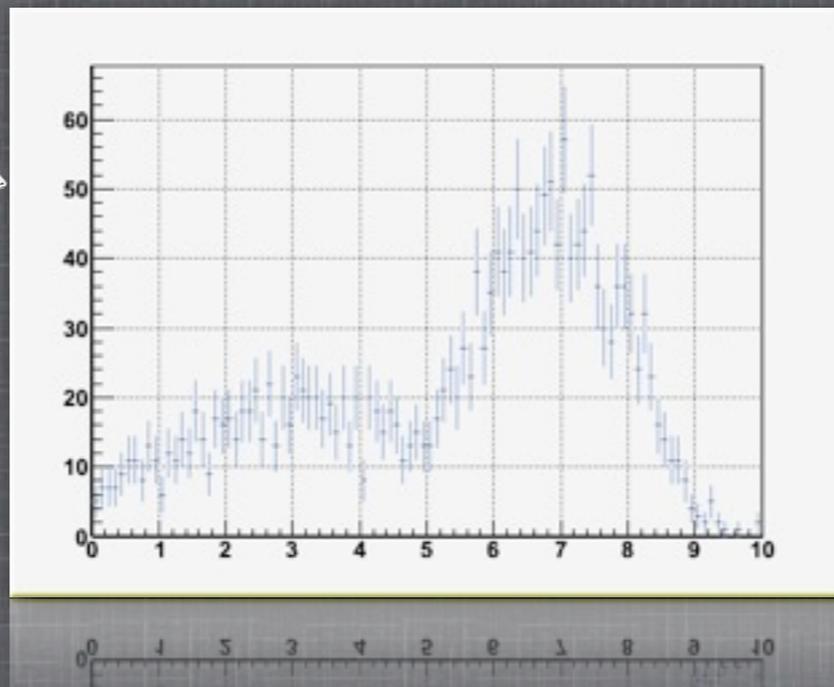
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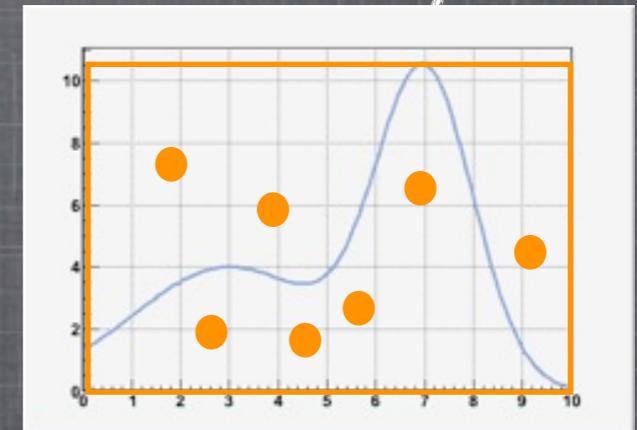


$$F(x) = \frac{\int^x f(u) du}{\int f(u) du}$$



Accept - Reject Method

(x_i, y_i) uniform in \square



accept x_i if $y_i < f(x_i)$
 $\rightarrow x_i$ 'f(x) distributed'!

What is It?

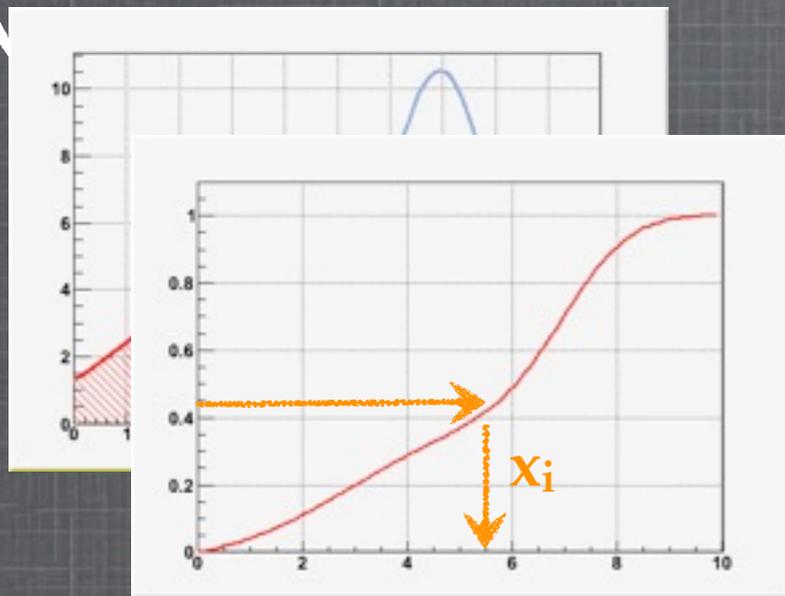
Monte Carlo method ...

- if $f(x)$ is a probability density function -

Inverse Method

x uniform in $[0,1[\Rightarrow F^{-1}(x)$ is 'f(x) distributed'

$F^{-1} \leftarrow F$ cumulative distribution function

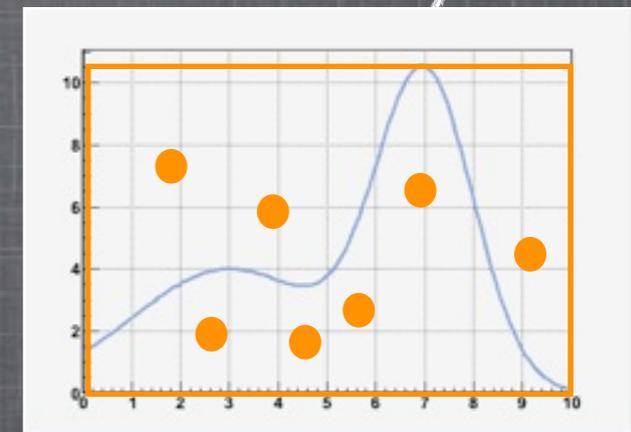


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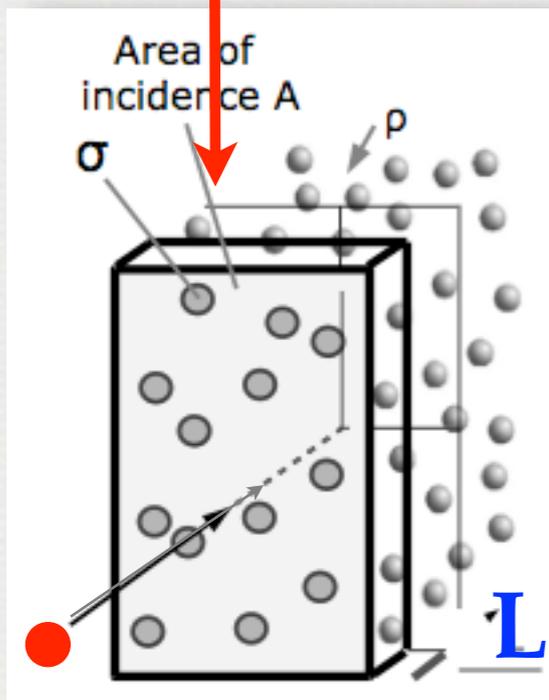


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What is It?

Monte Carlo method ...

One **particle** goes through **many others** (stopped)



- ➔ one cannot know where they are
- ➔ even if, it would cost a lot of computing power
- ➔ Quantum mechanism: interactions are probabilistic !
- ➔ statistical methods ...

Hypothesis :

Nuclei are uniformly distributed

Probability for the **particle** to travel undisturbed for a distance **L** ?

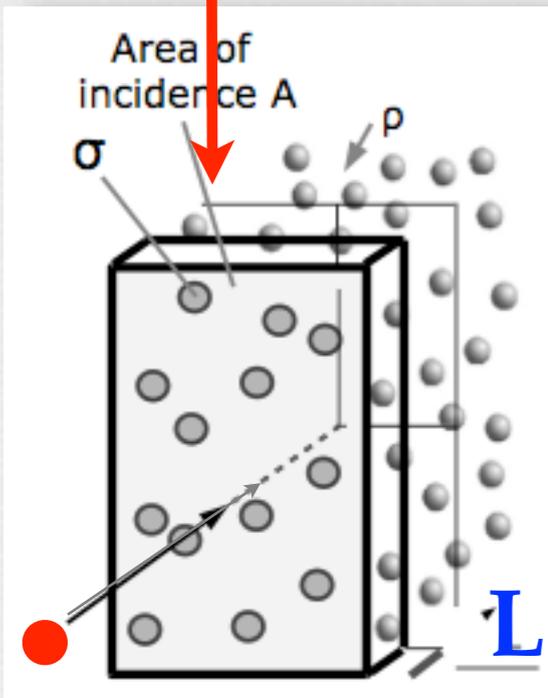
$$I_{\emptyset}(L) = \frac{\text{Number of particles reaching } L \text{ without 'interaction'}}{\text{Number of particles shot}}$$

frequentist's approach

What is It?

Monte Carlo method ...

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frequentist's approach

➔ scattering
➔ decay

What is It?

Monte Carlo method ...

After playing a bit $\Rightarrow I_{\circ}(L) = \exp(-\rho \cdot L \cdot \sigma)$

ρ macroscopic density of matters

σ microscopic cross section of the interaction process

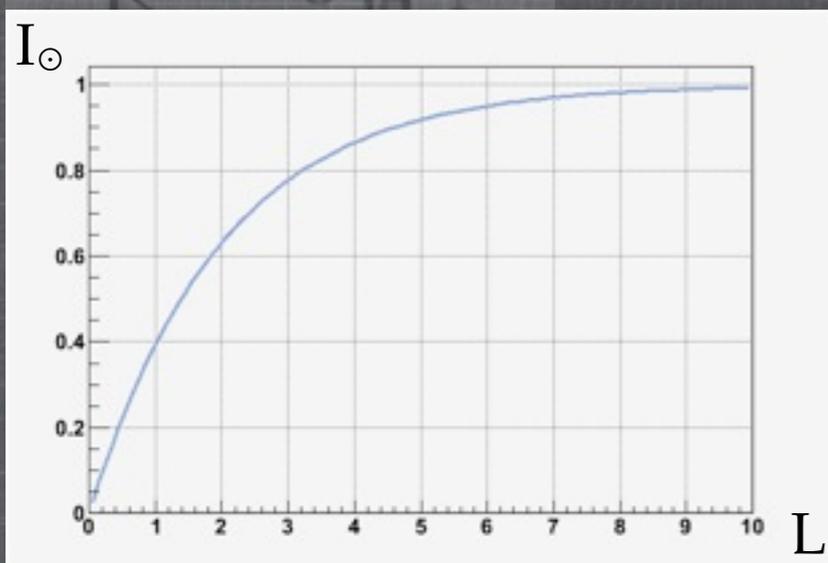
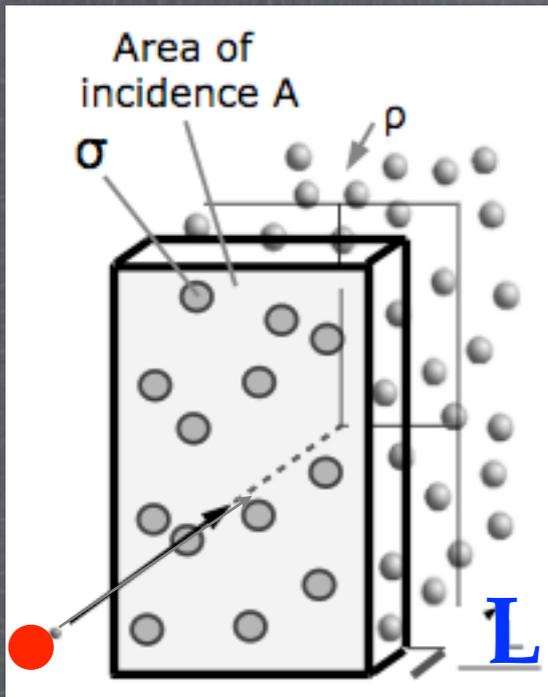
σ (type particle, energy, ...) - ex : $\sigma = \pi r^2$

\rightarrow it relies on models, measurements (database)

Probability to have an interaction at L :

$$\Rightarrow I_{\circ}(L) = 1 - I_{\circ}(L) = 1 - \exp(-L/\lambda)$$

where λ (type ...) is the mean free path length



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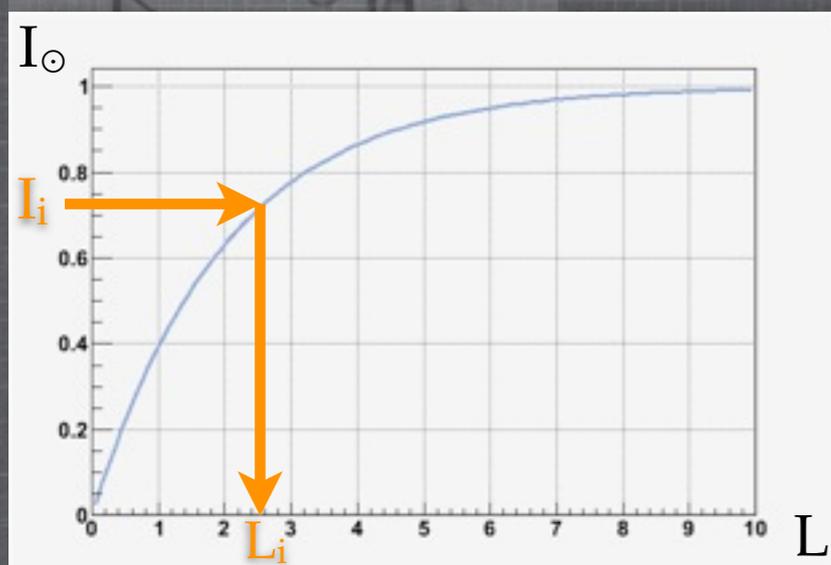
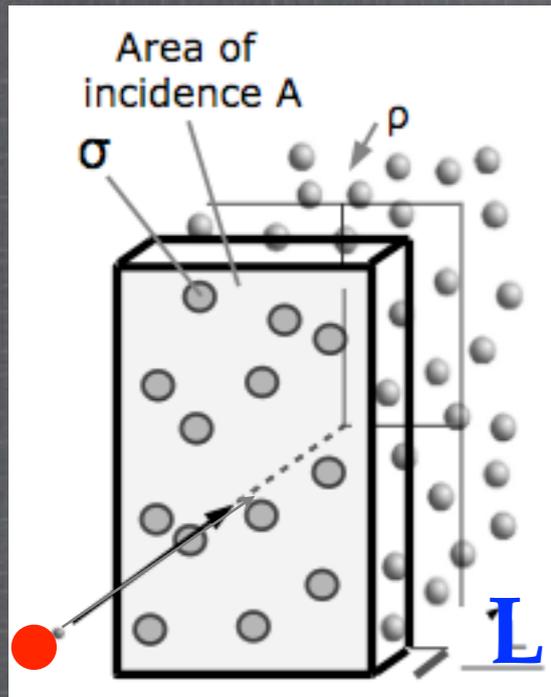
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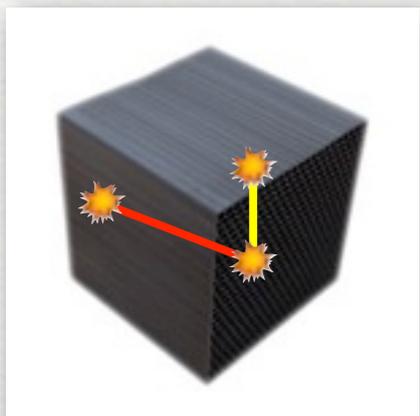
to simulate one shot,
select randomly $I_i \rightarrow L_i$

What is It?

Monte Carlo method ...

General case: competition between several processes iI

iI_0 the probability of having an interaction at distance L

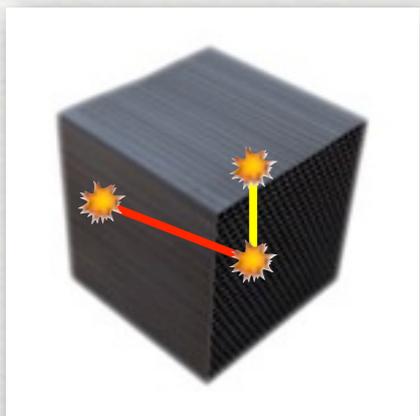
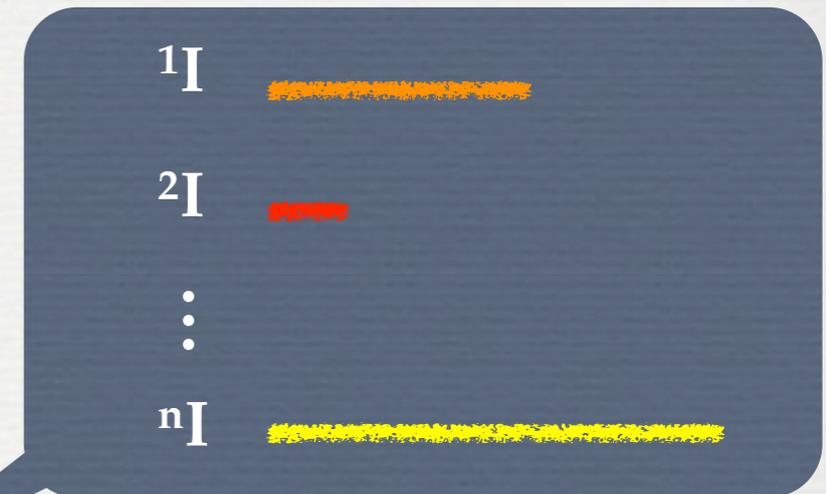


What is It?

Monte Carlo method ...

General case: competition between several processes iI
 iI_0 the probability of having an interaction at distance L

- start values for incident particle
- get value for ρ, σ
- sample L_i from iI_0
- smallest L_s selects the process sI
- transport particle undisturbed by L_s
- simulate **interaction**

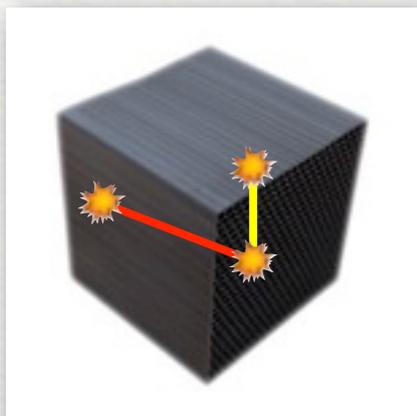
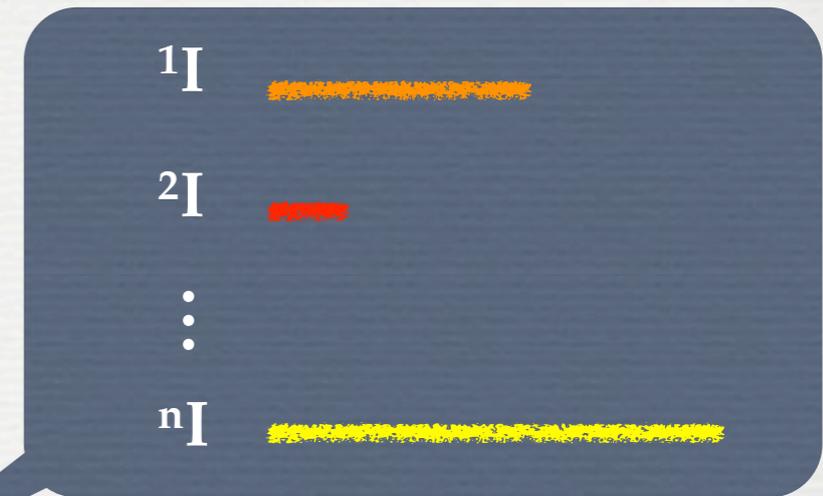


What is It?

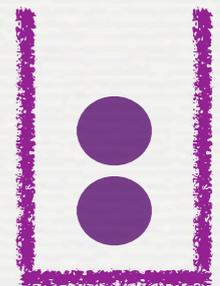
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secondary particles



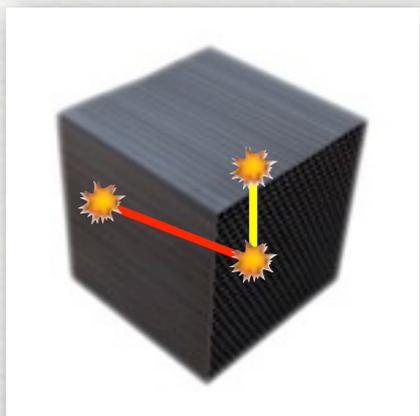
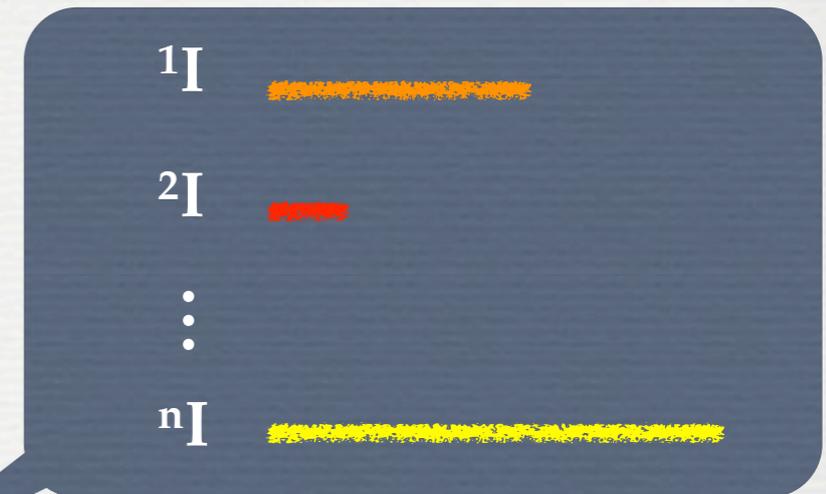
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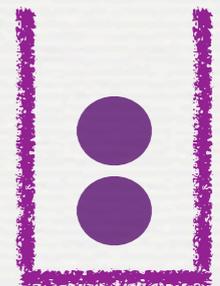
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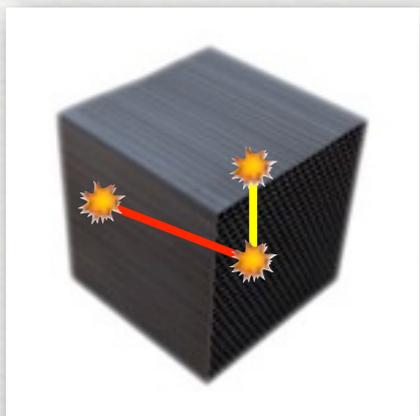
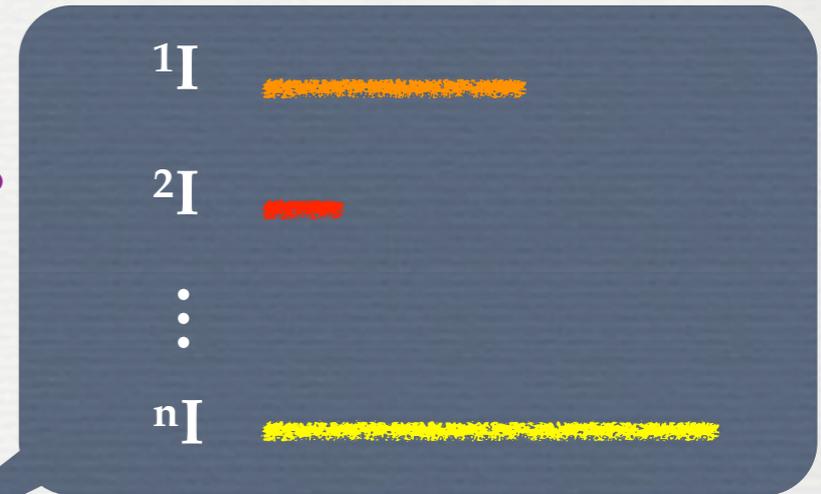


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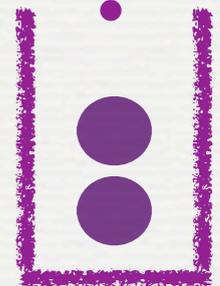
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\rightarrow secondary particles



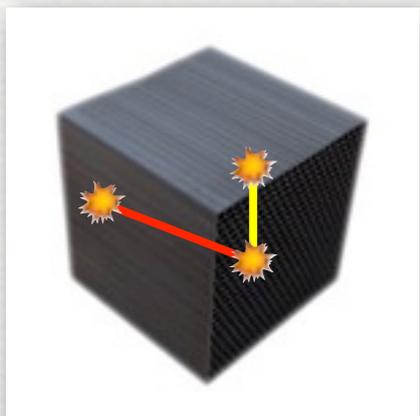
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Monte Carlo method ...

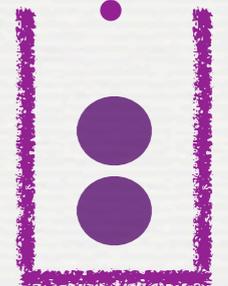
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Core of the Monte Carlo Method !

- start values for incident particle $\leftarrow \bullet$
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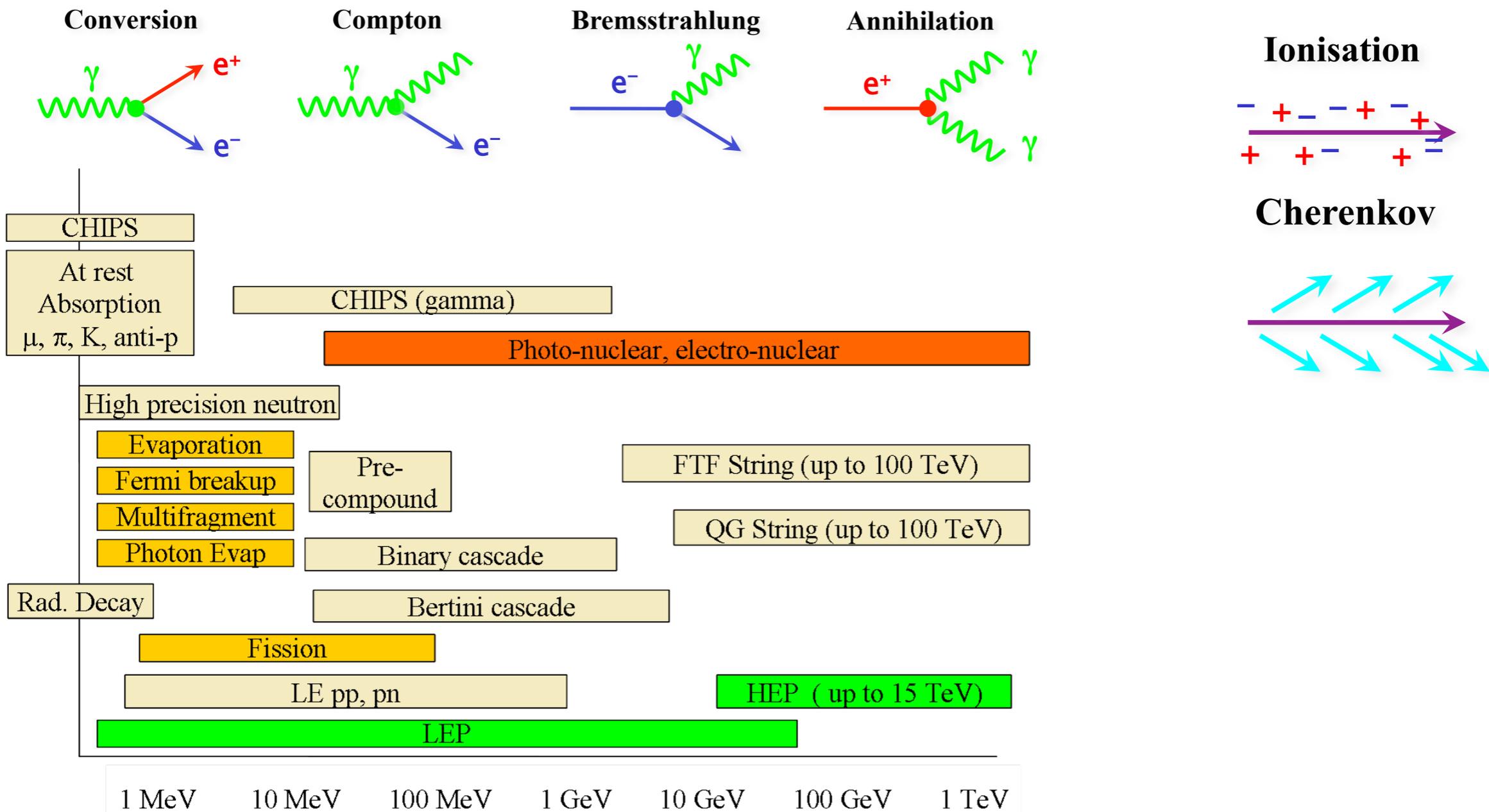


\rightarrow secondary particles



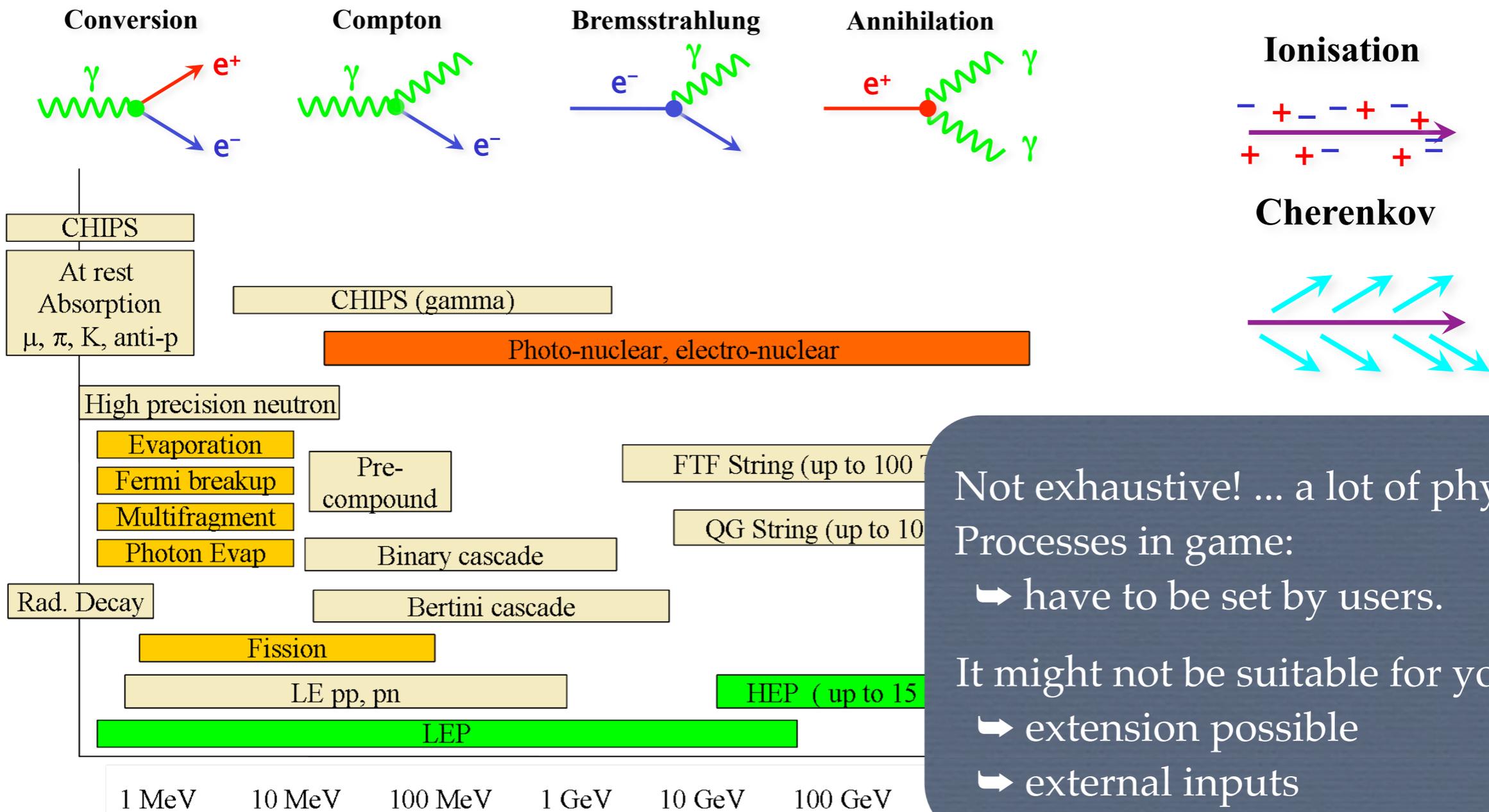
What is It? A quick overview of processes in G4

Electromagnetic, hadronic, optical, transport, decay ...
 (based on models and / or databases-measurements ... expandable !)



What is It? A quick overview of processes in G4

Electromagnetic, hadronic, optical, transport, decay ...
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Not exhaustive! ... a lot of physics!
 Processes in game:
 ➔ have to be set by users.
 It might not be suitable for you!
 ➔ extension possible
 ➔ external inputs

What is It?

Some general statements

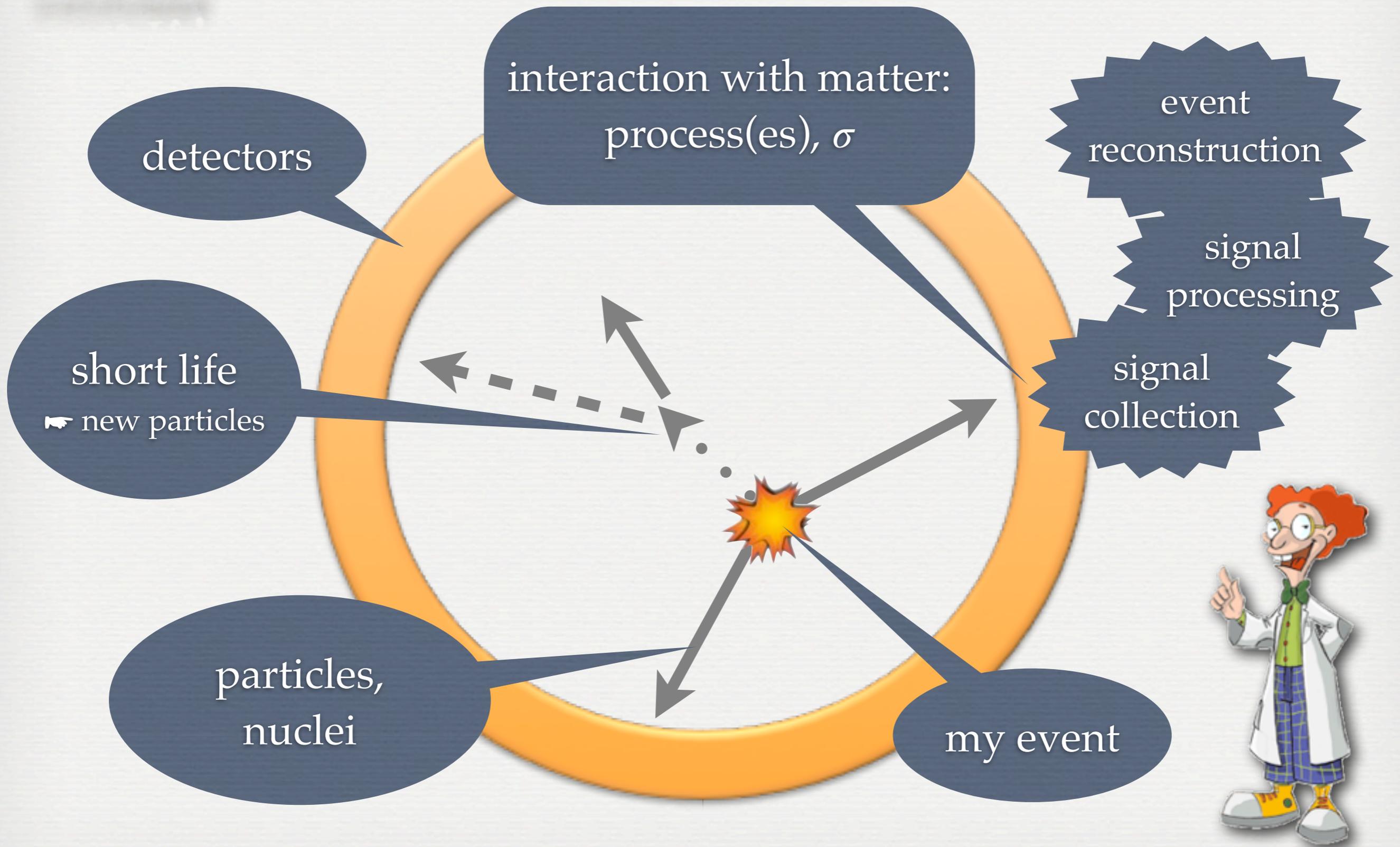
Monte Carlo into the *game*

Geant4 some vocabulary

The Geant4 machine

What is It?

the world to be modeled

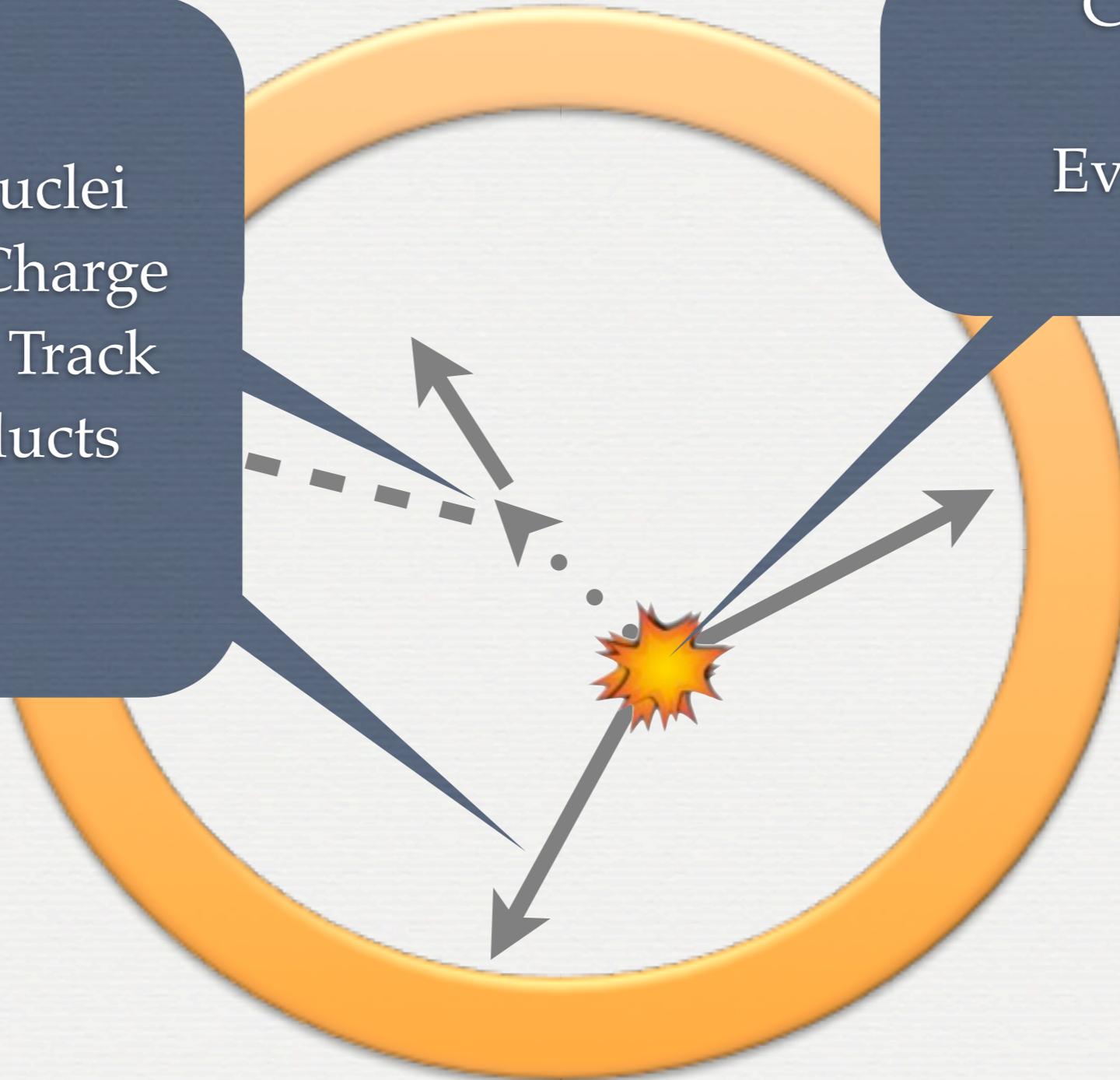


What is It?

the world to be modeled

Particles, Nuclei
Mass, Spin, Charge
Momentum, Track
Decay products
...

Collisions
Vertex
Events, Run
...

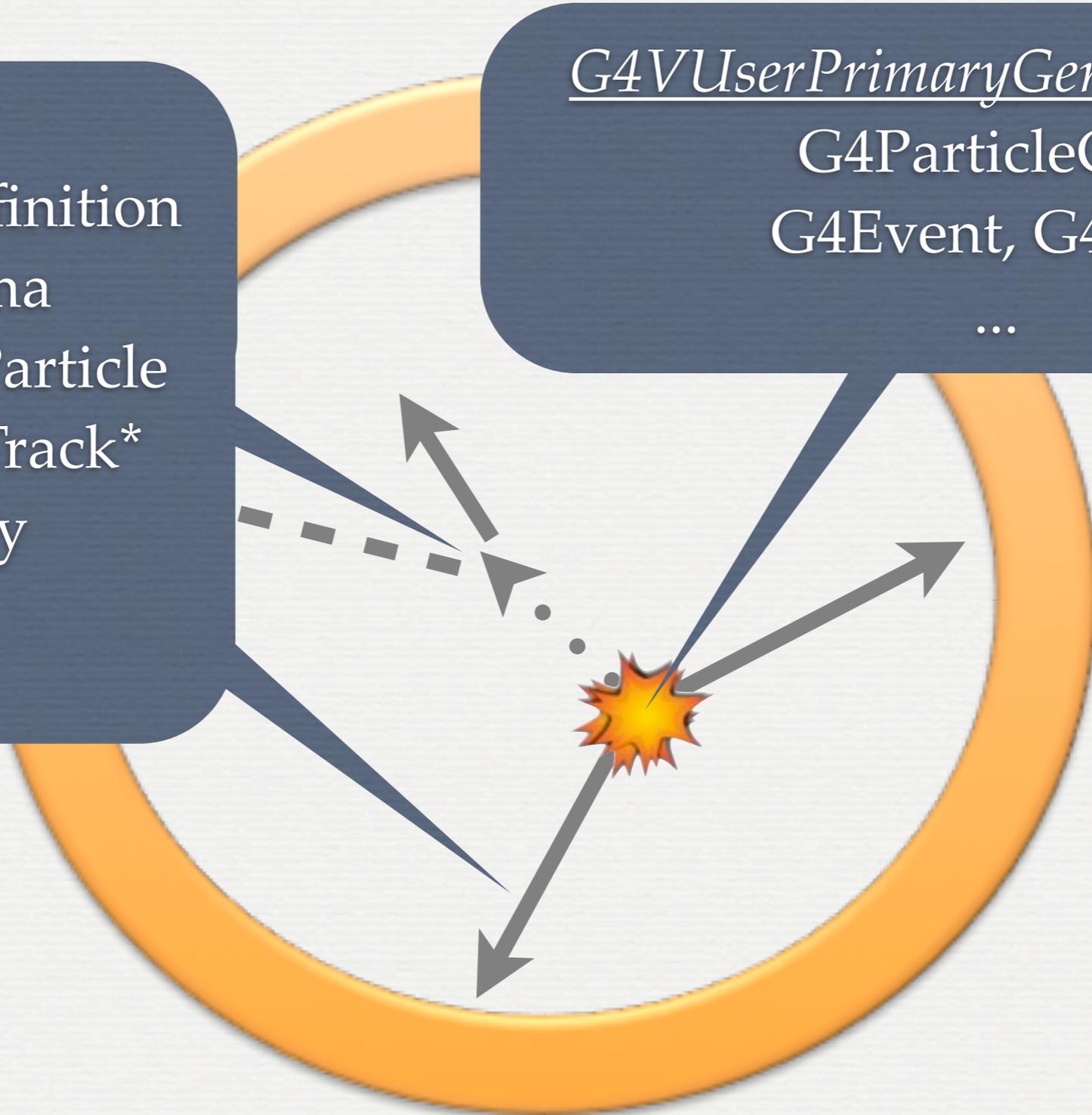


What is It? The GEANT4 [G4] world

G4ParticleDefinition
G4Gamma
G4DynamicParticle
G4Step, G4Track*
G4Decay
...

G4VUserPrimaryGeneratorAction

G4ParticleGun
G4Event, G4Run
...

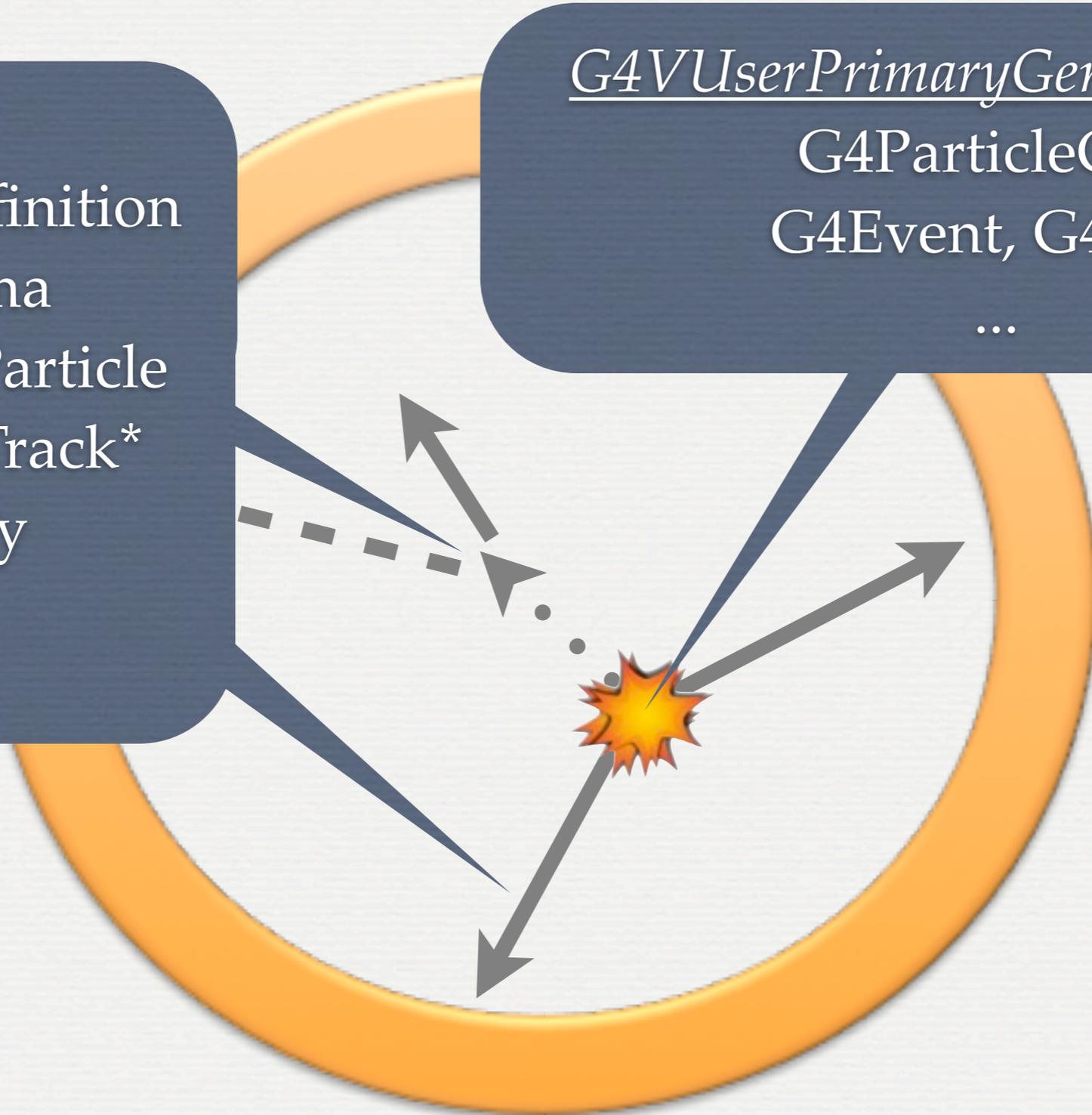


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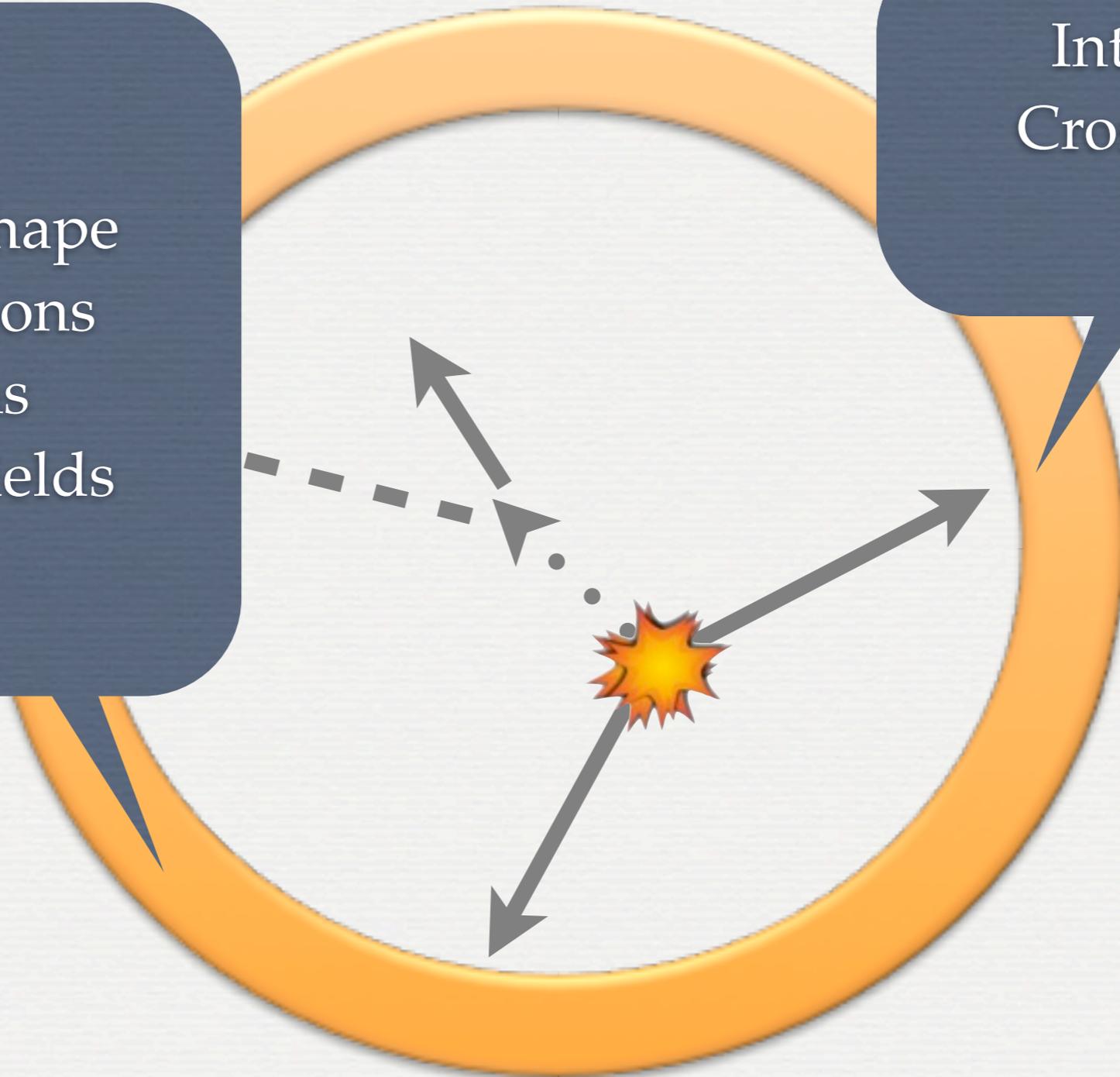
* a G4Track is not a collection of G4Step but a snapshot of a particle within its environment

What is It?

the world to be modeled

Setup
Material, Shape
Compositions
Positions
Magnetic fields
...

Interactions
Cross Sections
...



What is It? The GEANT4 [G4] world

G4VUserDetectorConstruction

G4Material, G4Solid

G4LogicalVolume,

G4VPhysicalVolume

G4ThreeVector, G4RotationMatrix

G4Field

...

G4VUserPhysicsList

G4VProcess

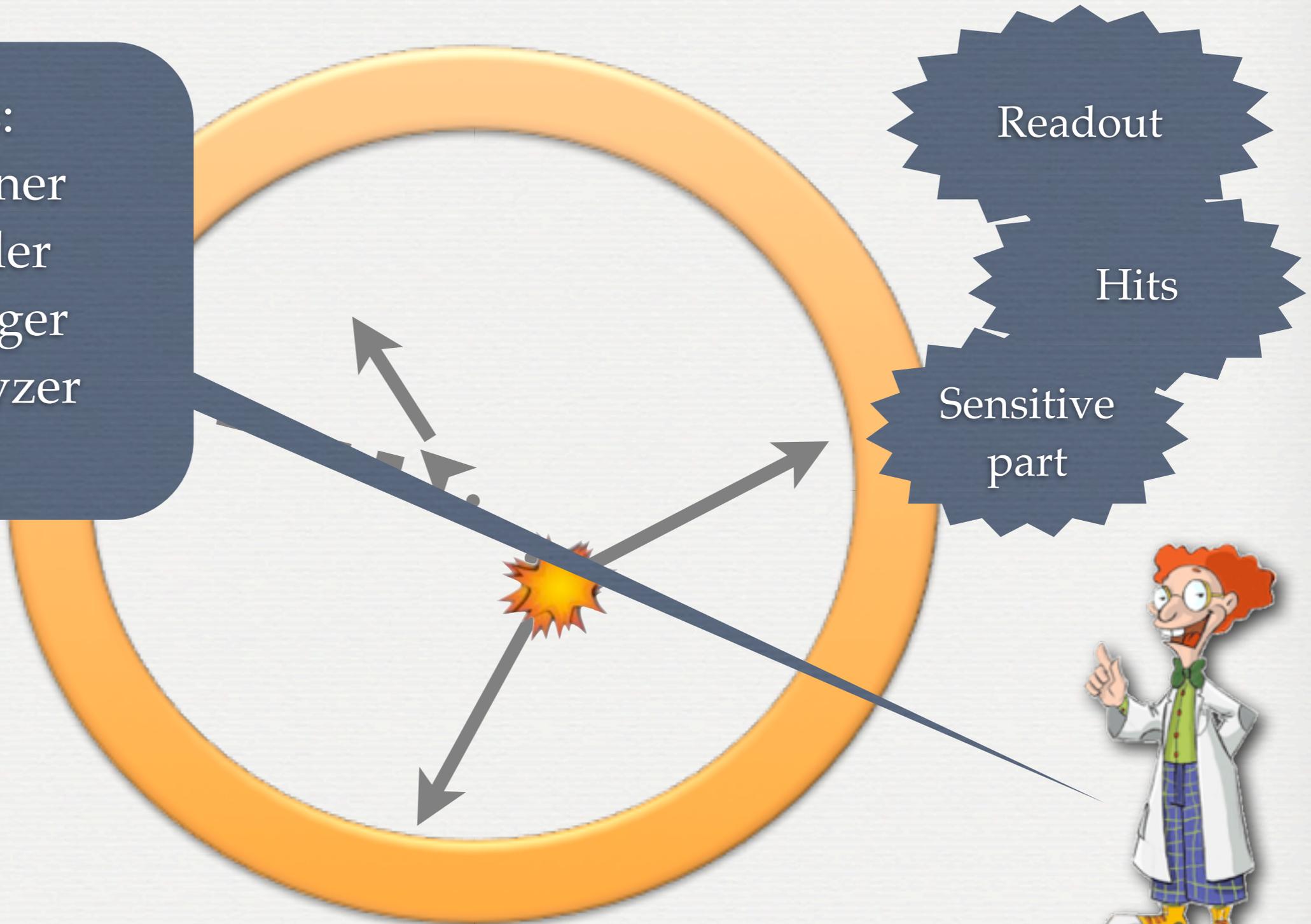
...



What is It?

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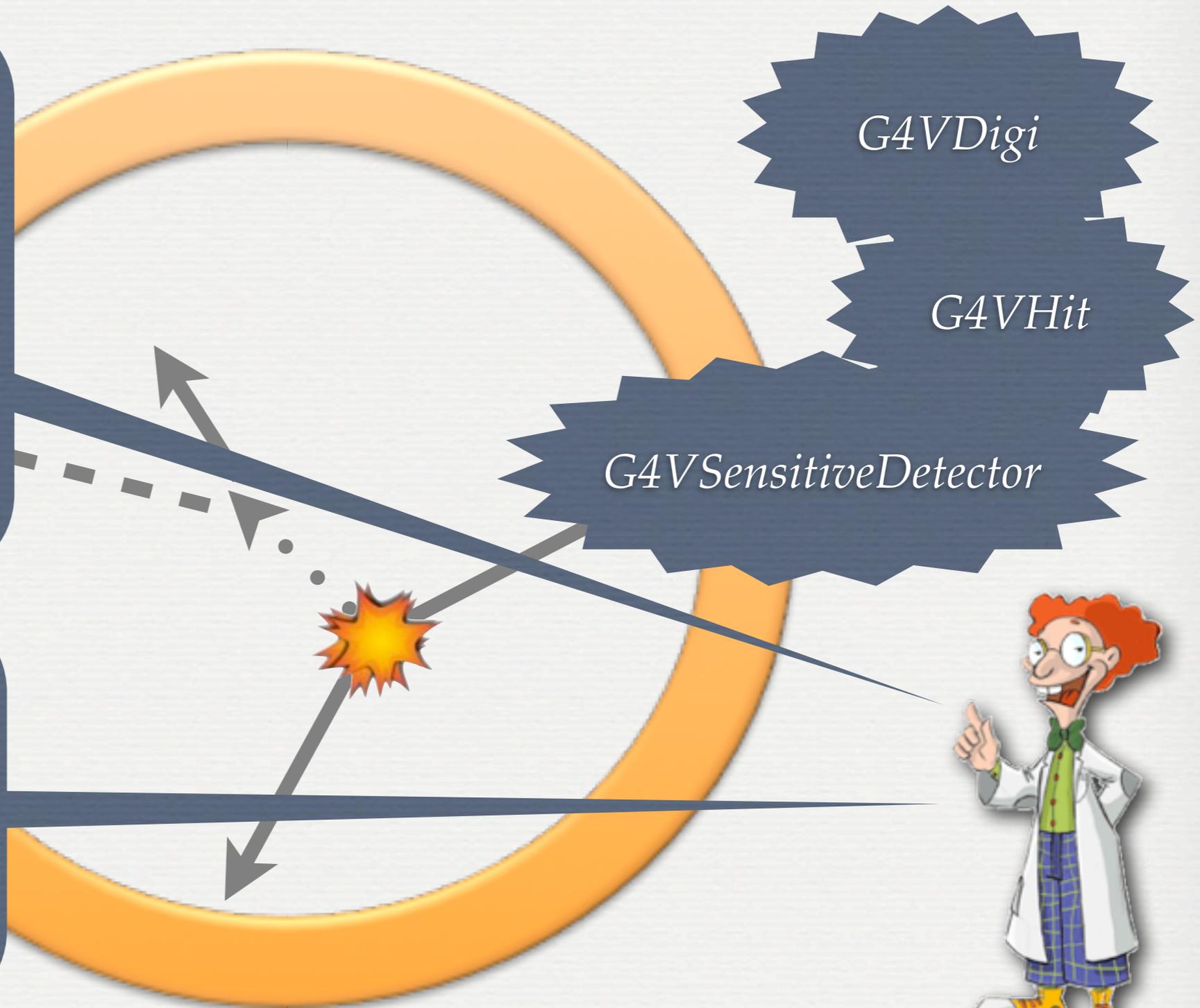
He is:
a designer
a builder
a manager
an analyzer
...



What is It? The GEANT4 [G4] world

G4 inner control
G4RunManager
G4EventManager
G4SteppingManager
G4TrackingManager
...

User's Actions
G4VUserRunAction
G4VUserEvenAction
...





What is It?

Some general statements

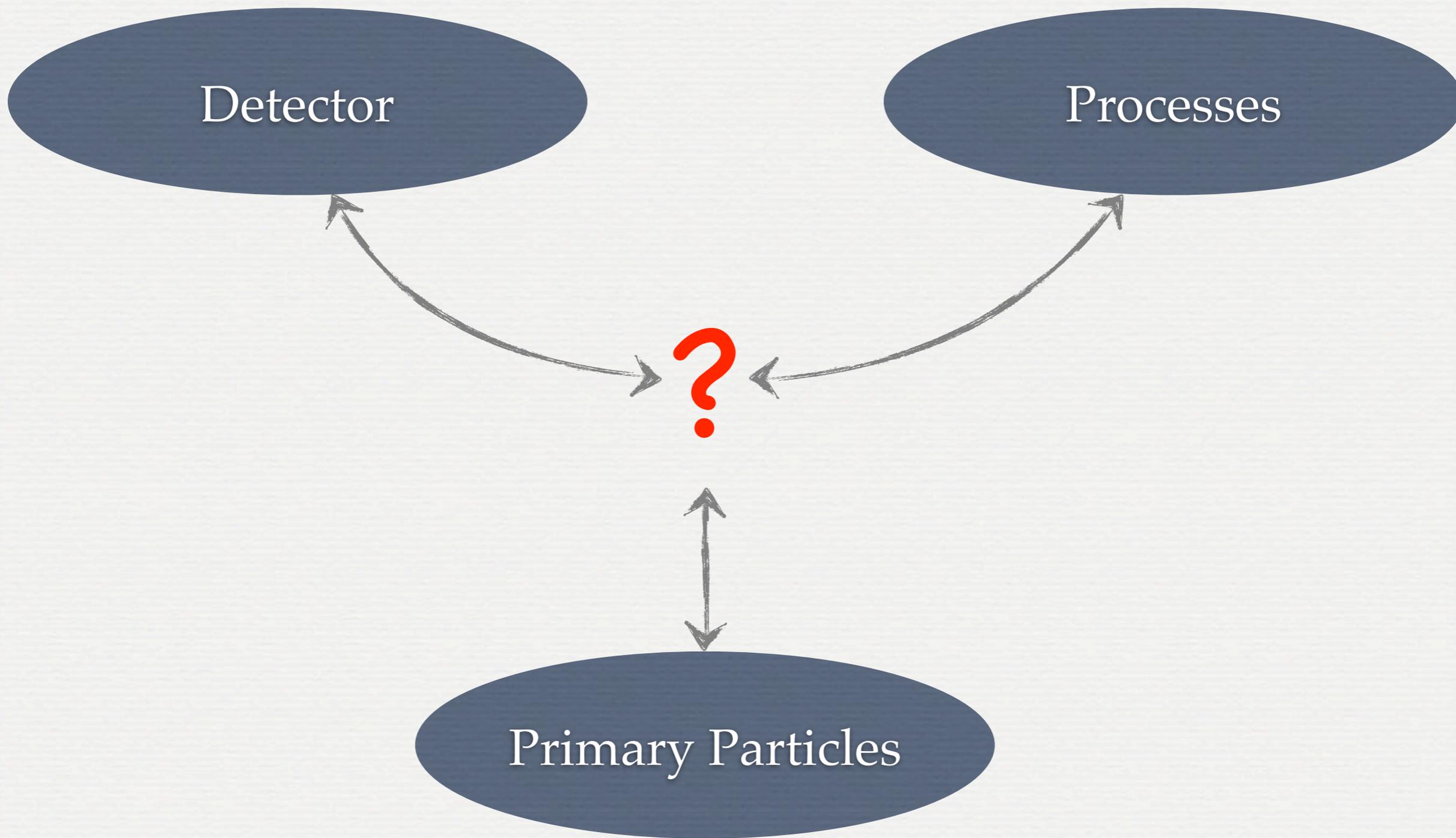
Monte Carlo into the *game*

Geant4 some vocabulary

The Geant4 machine

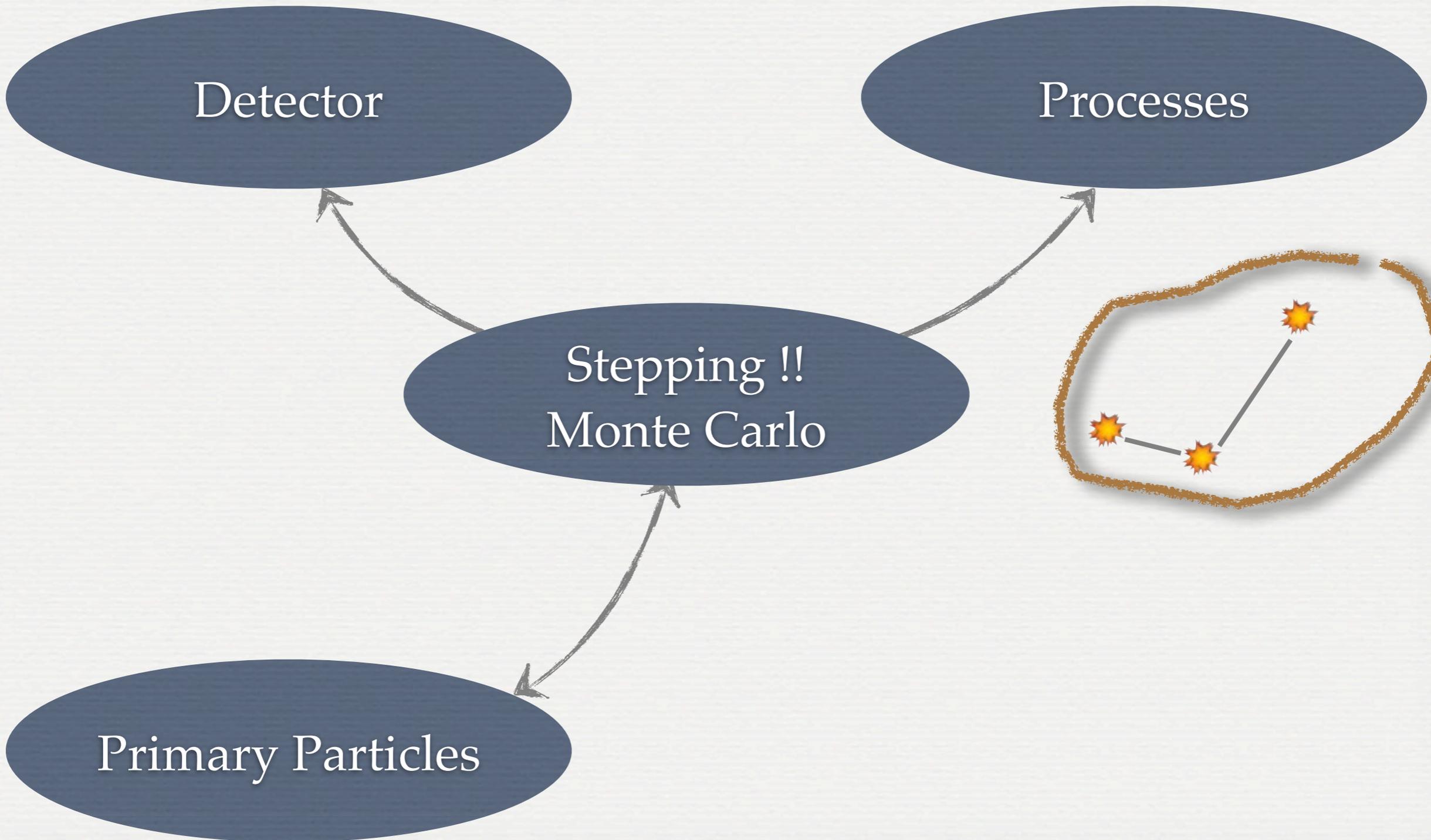
What is It?

ALL G4 Things together



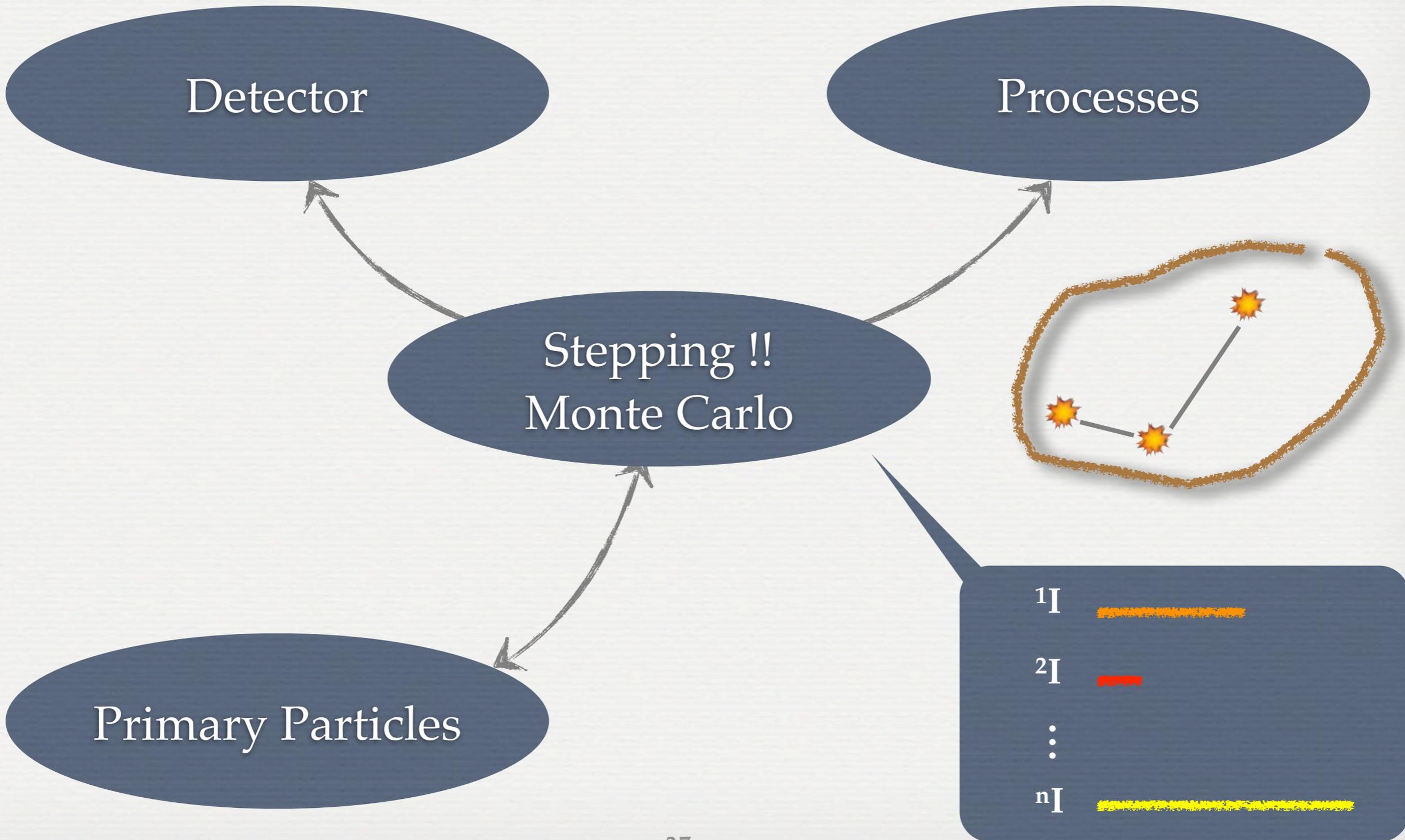
What is It?

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What is It?

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What is It?

ALL G4 Things together



- First Phase, initialization:

- ☑ Definition of the full setup
- ☑ What particles, What processes they see
- ☑ Primary generator in action

- Then Main loop :

/run/BeamOn 10000

- Start run # 1 : conditions of simulation fixed*
- Start event # i
 - primaries randomly generated and tracked
- Stop event # i
- Stop run# 1 -

* geometry, processes

What is It?

ALL G4 Things together



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public G4UserDetectorConstruction  
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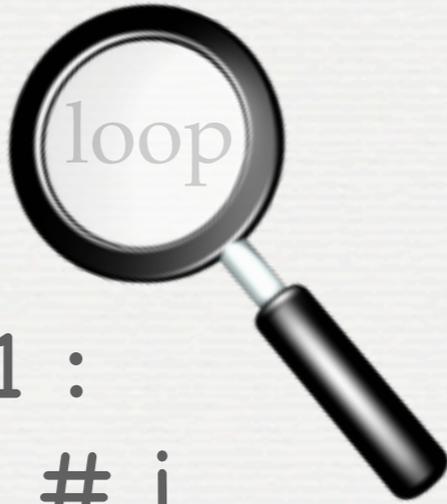
* geometry, processes

What is It?

ALL G4Things together



'Loupe' on the main loop



Start run # 1 :

Start event # i

Start **track** # j

Start **step** # k

Stop **step** # k

Stop **track** # j

Stop event # i

Stop run # 1

k Track ID

Track stack

active

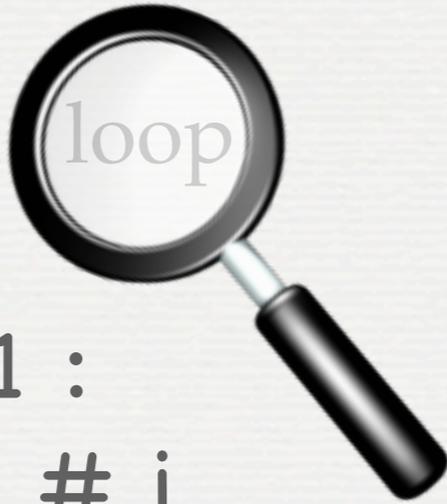
waiting

What is It?

ALL G4Things together



'Loupe' on the main loop



Start run # 1 :

Start event # i

Start track # j

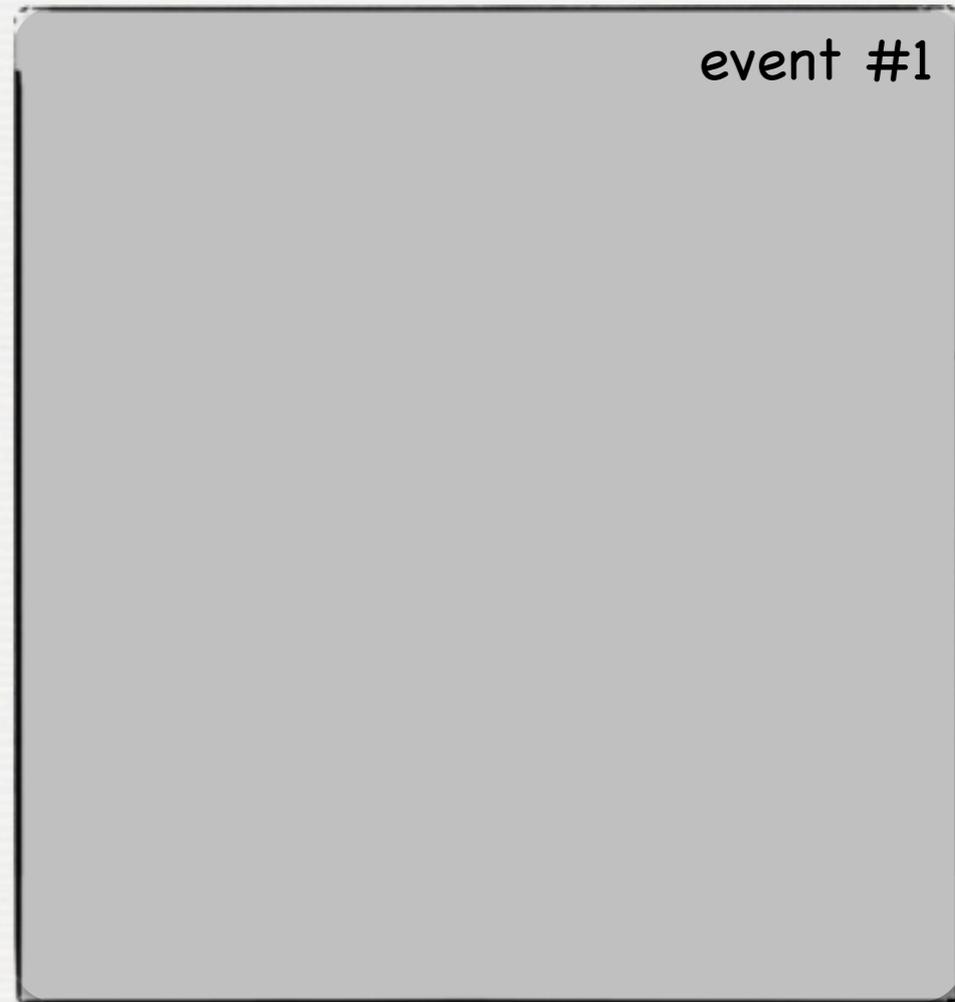
Start step # k

Stop step # k

Stop track # j

Stop event # i

Stop run # 1



k Track ID

Track stack

active

waiting

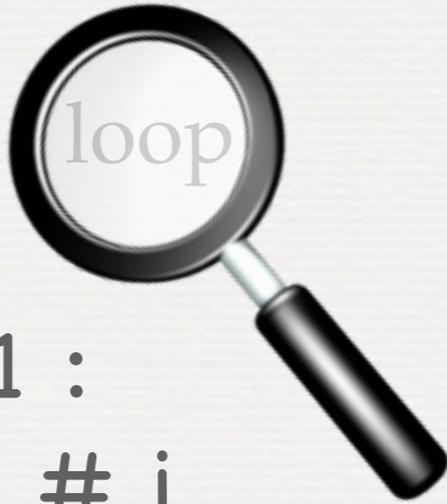


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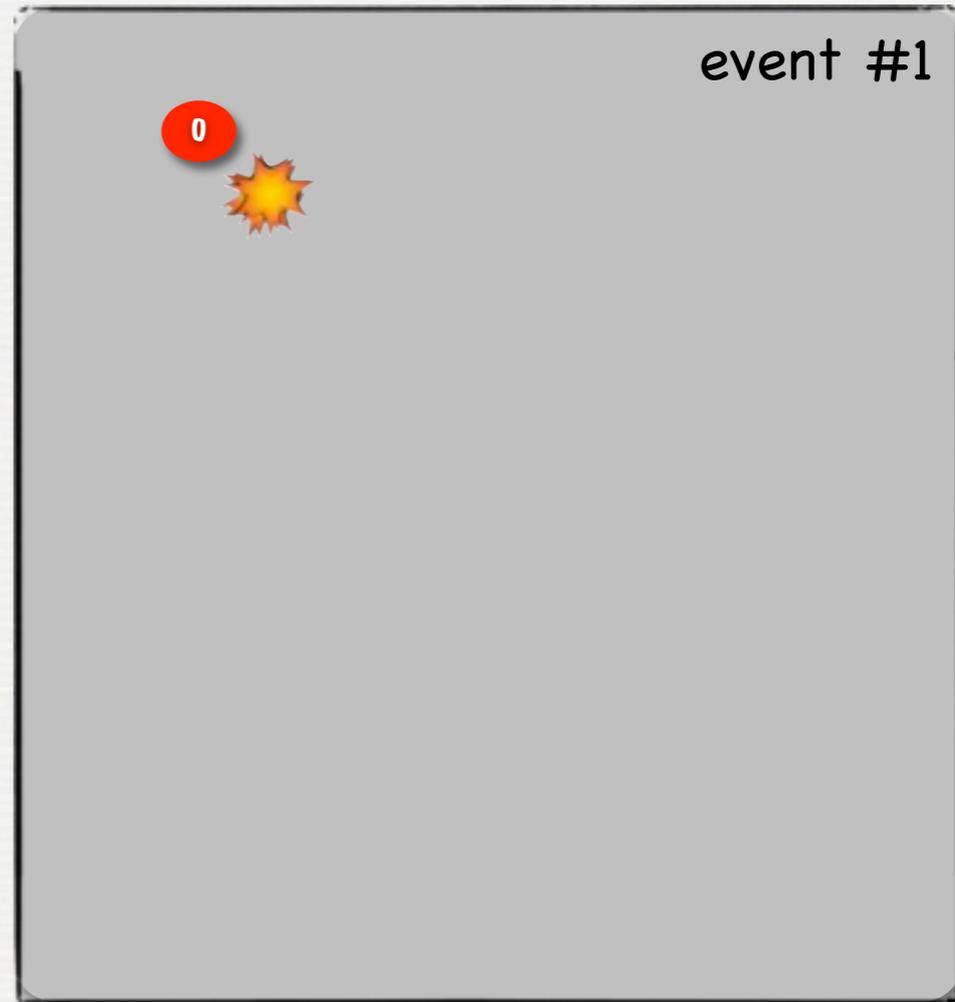


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waiting

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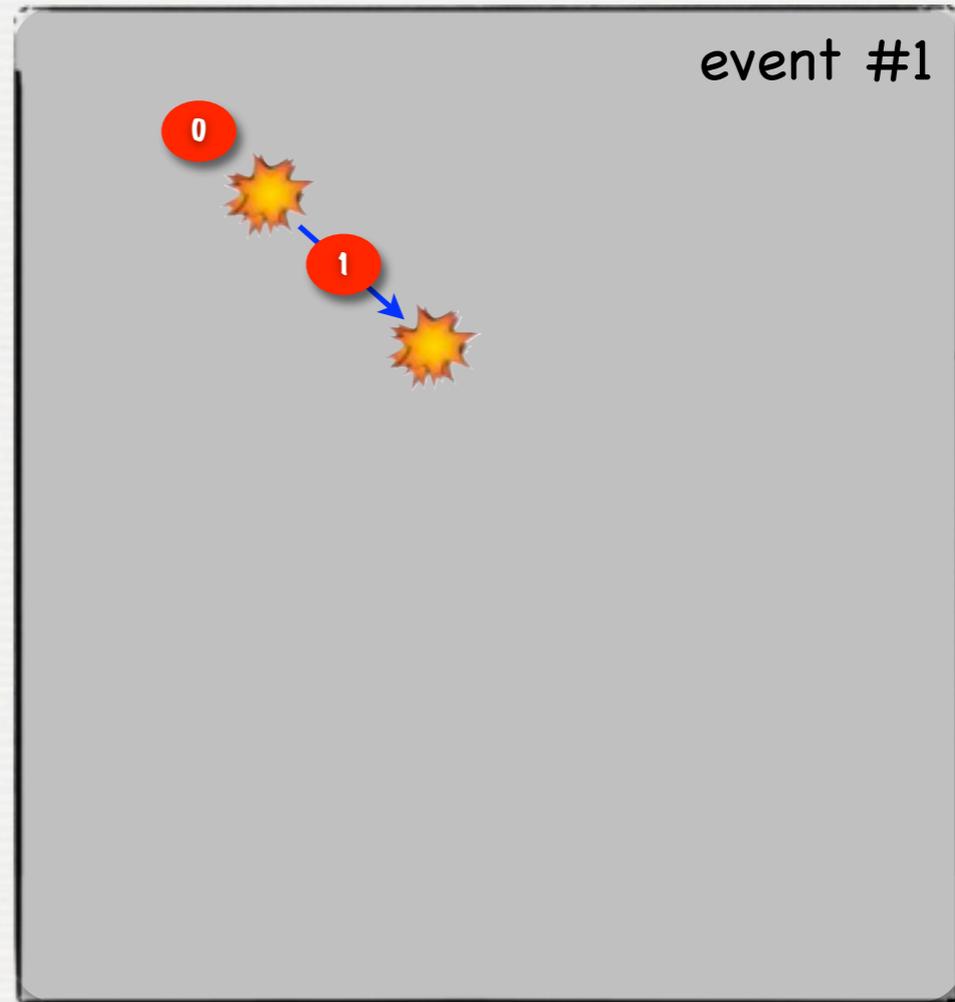


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1
active

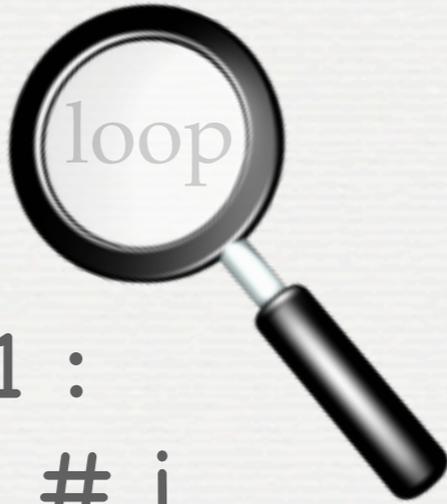
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waiting

What is It?

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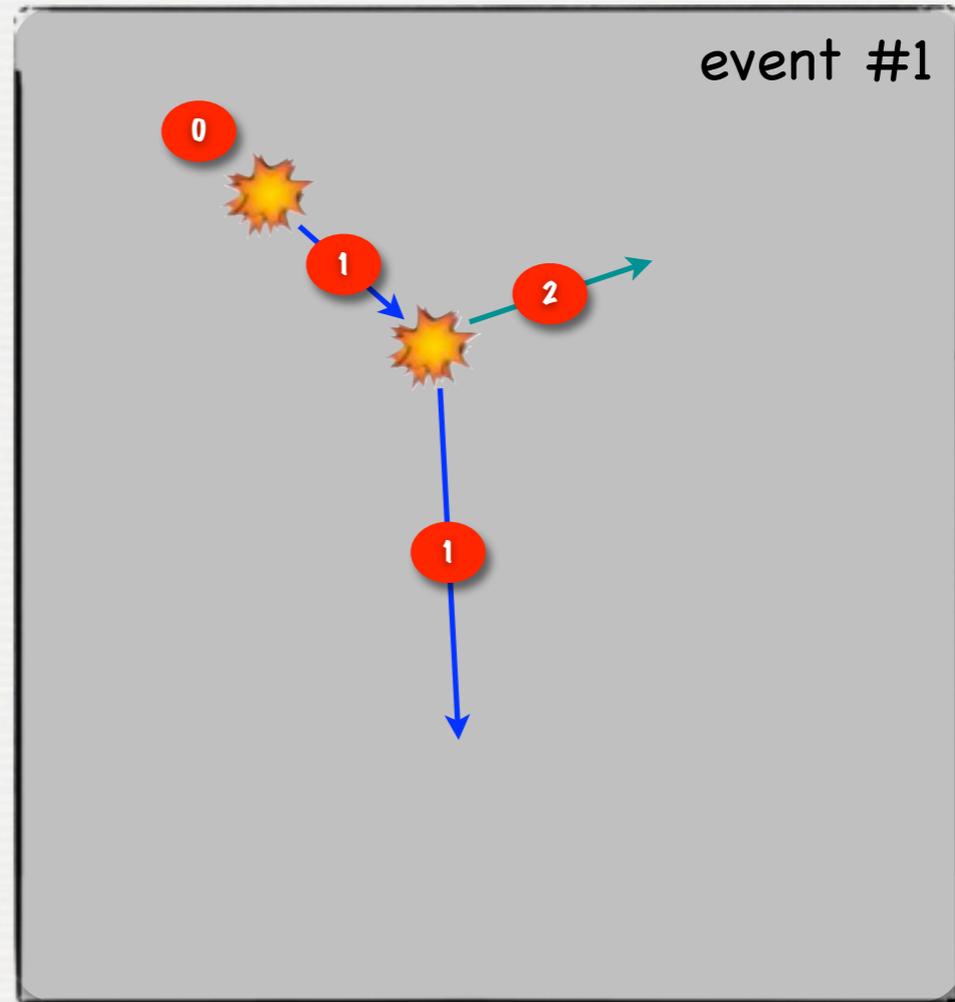


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Track stack

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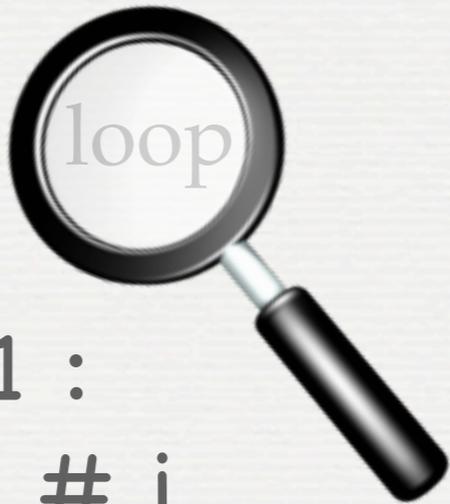
2
waiting

What is It?

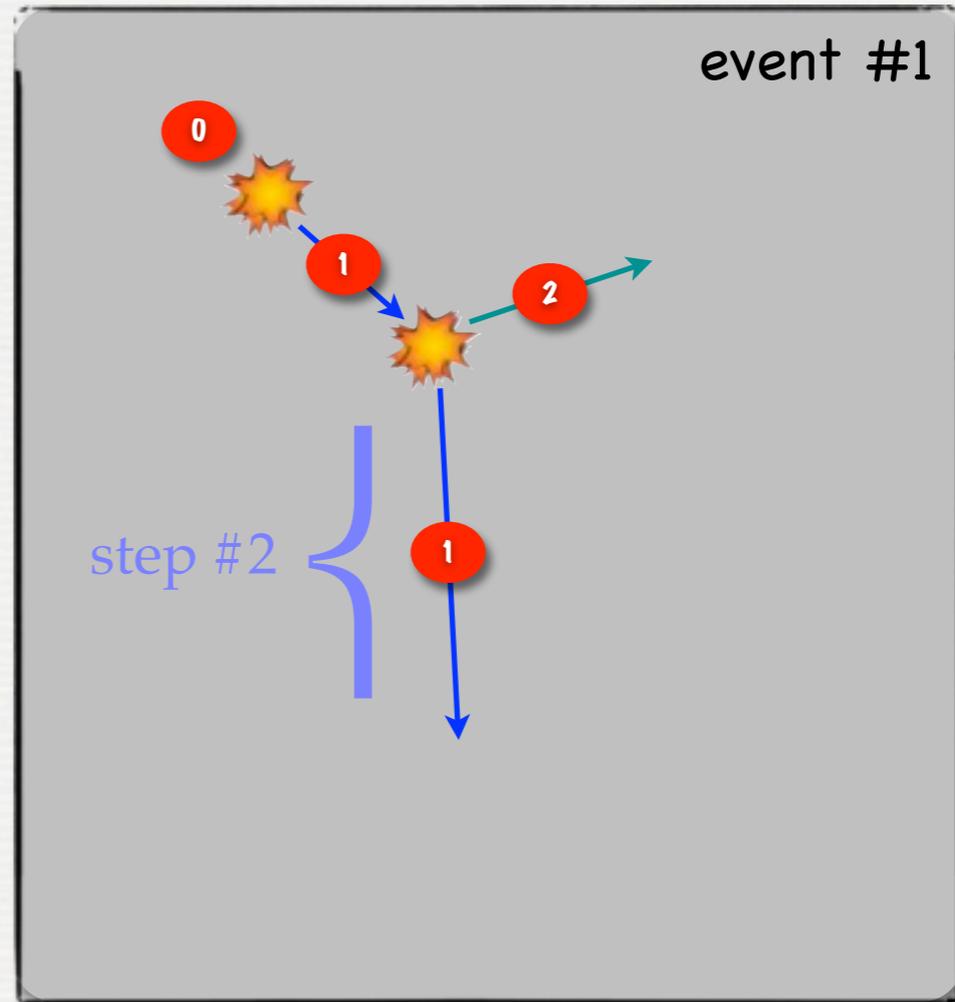
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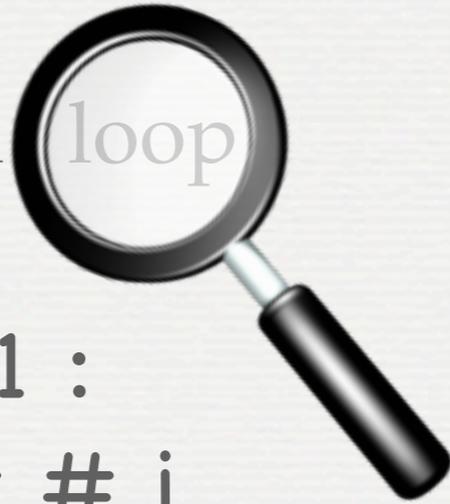
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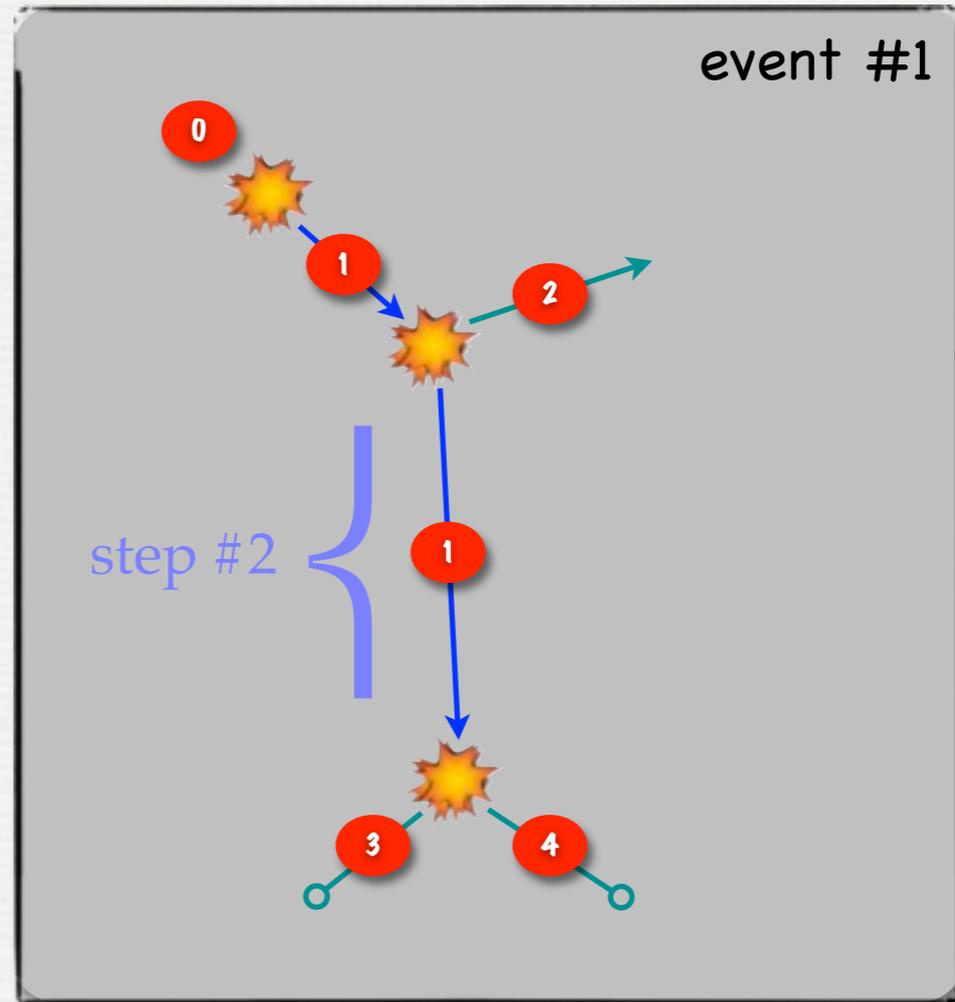


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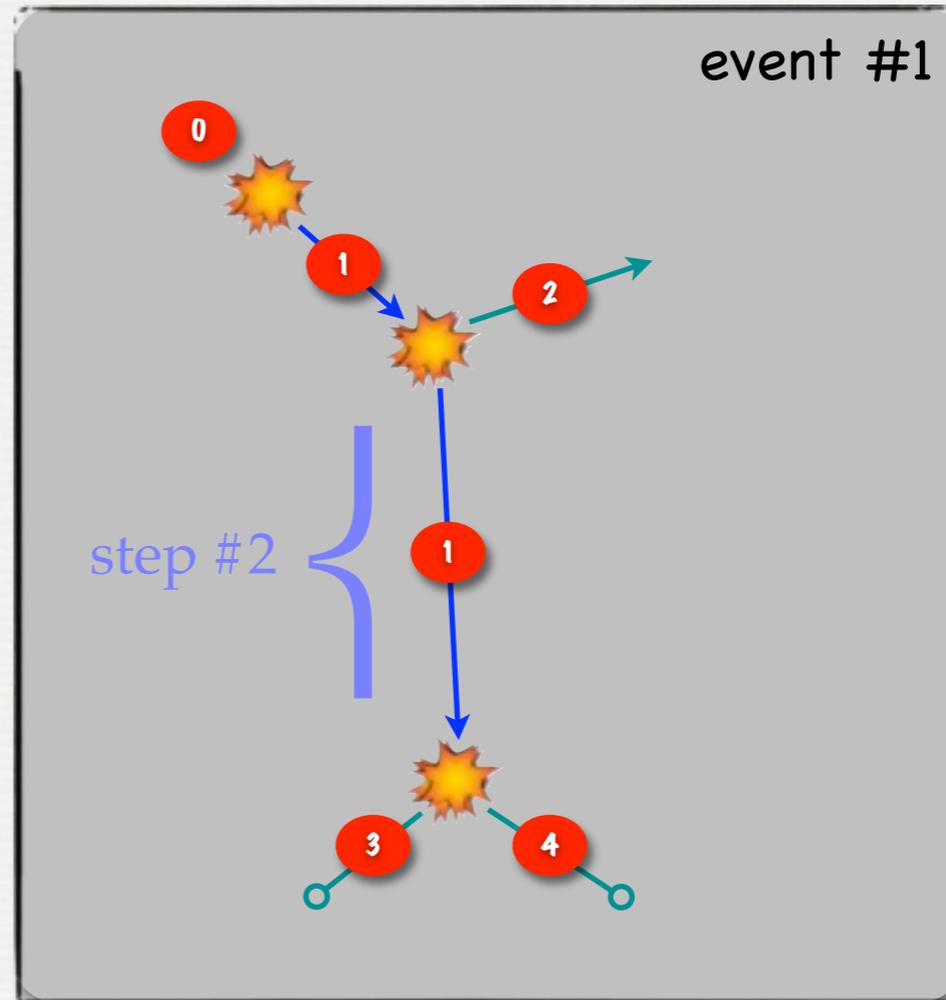


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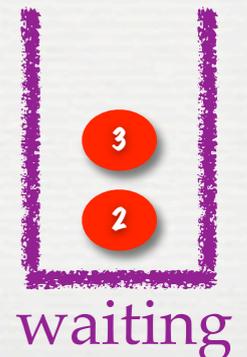


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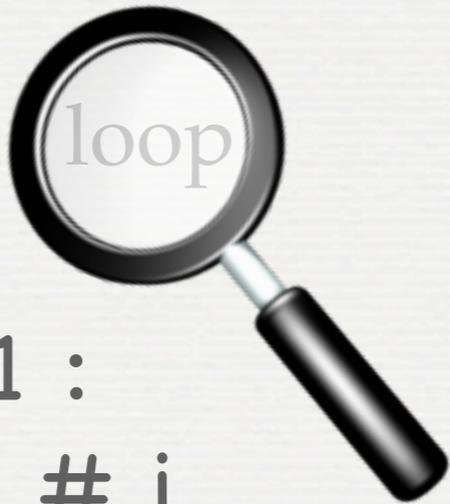
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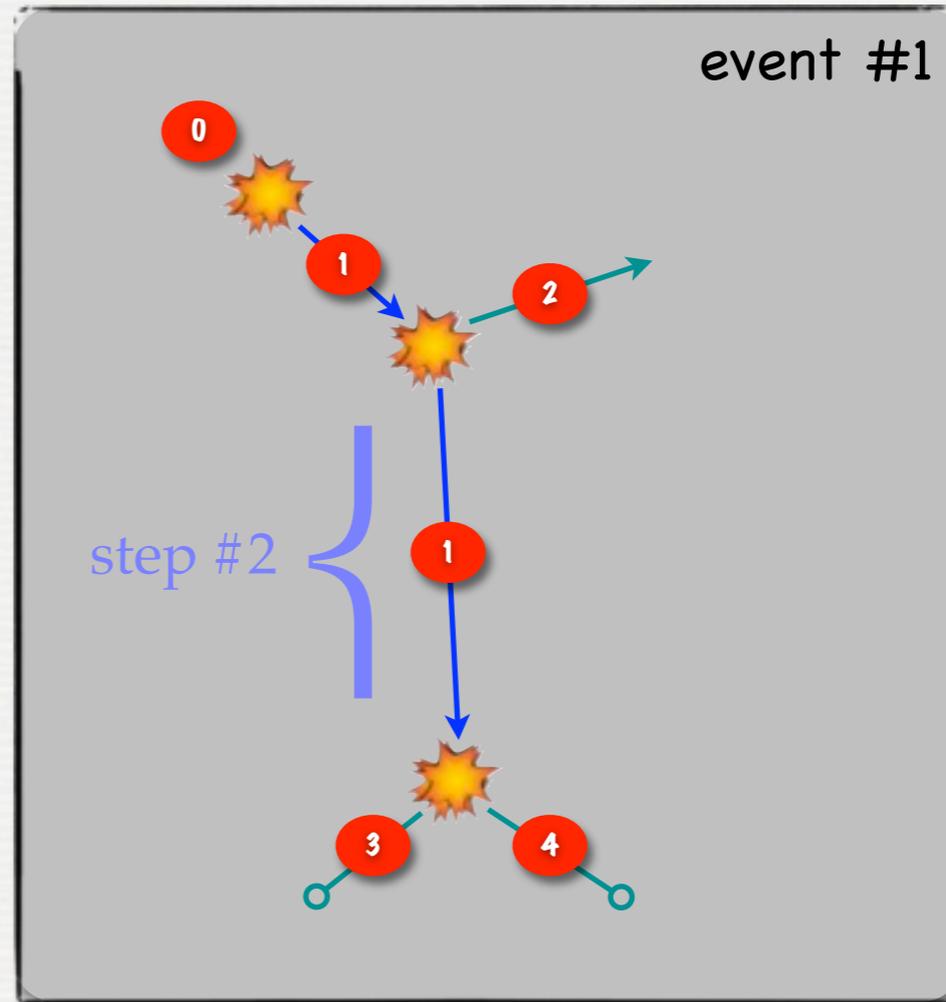
ALL G4Things together



'Loupe' on the main loop



- Start run # 1 :
- Start event # i
- Start track # j
- Start step # k
- Stop step # k
- Stop track # j
- Stop event # i
- Stop run # 1



k Track ID

Track stack

active **3**

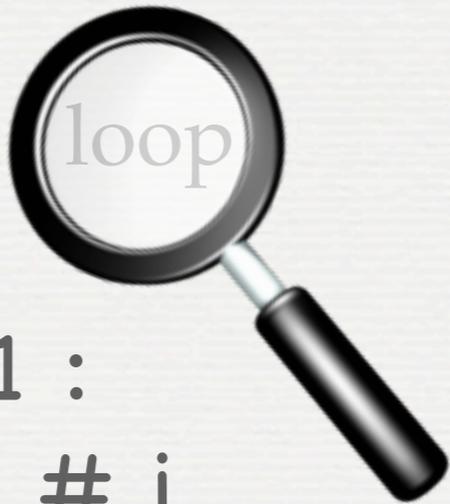
waiting **2**

What is It?

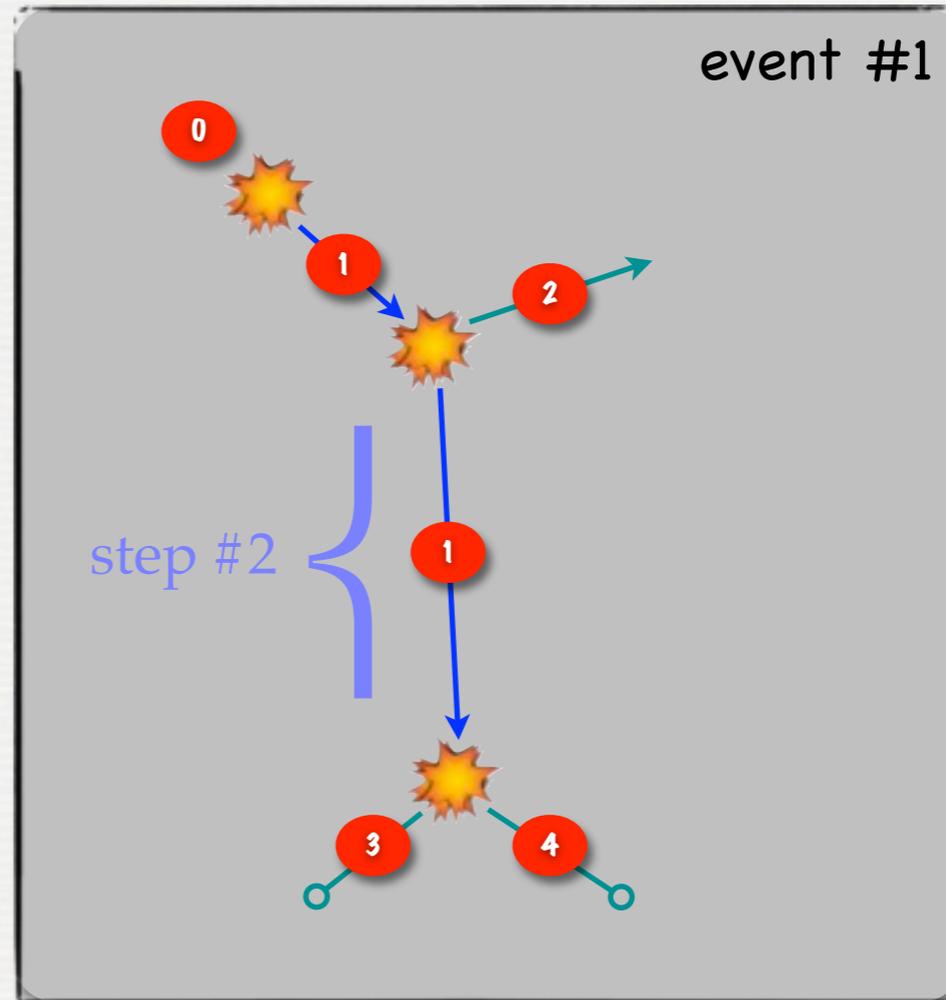
ALL G4Things together



'Loupe' on the main loop



- Start run # 1 :
- Start event # i
- Start **track** # j
- Start **step** # k
- Stop **step** # k
- Stop **track** # j
- Stop event # i
- Stop run # 1



k Track ID

Track stack

2
active

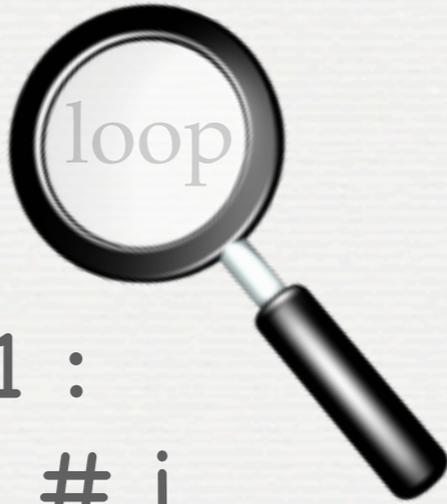
L
waiting

What is It?

ALL G4Things together

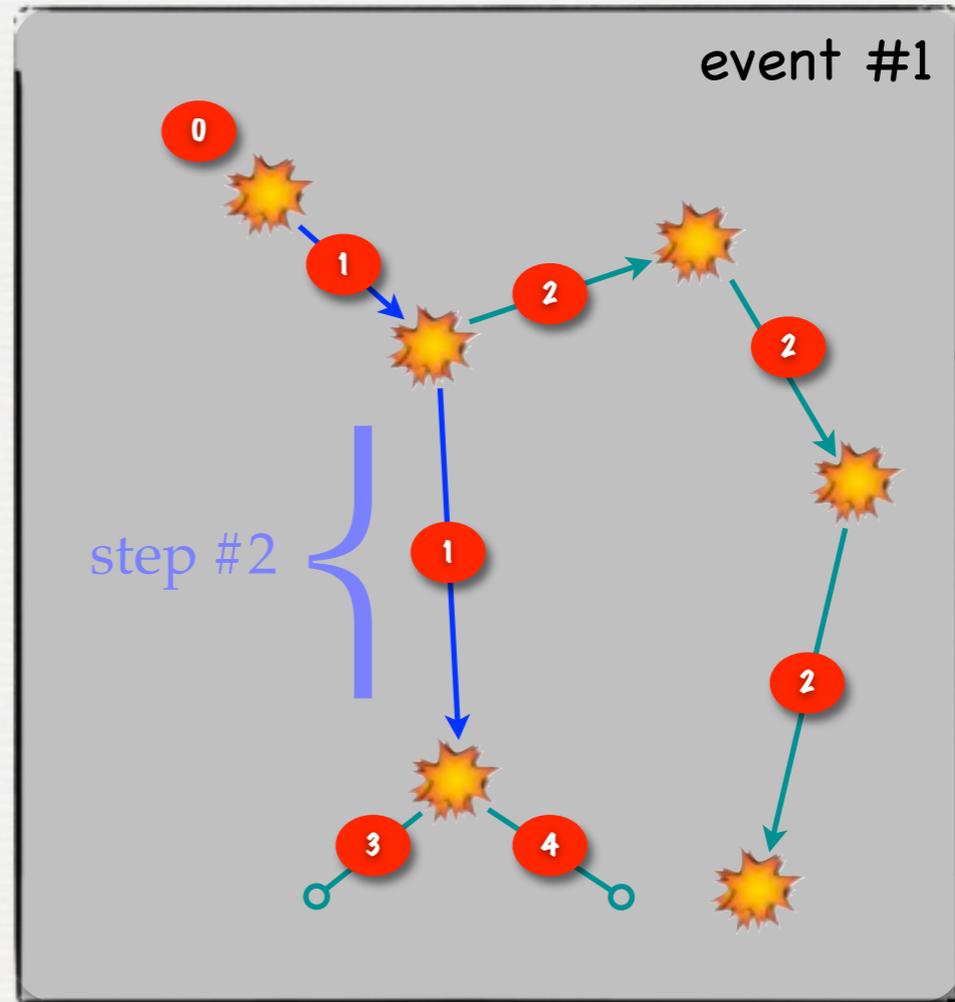


'Loupe' on the main loop



- Start run # 1 :
- Start event # i
- Start **track** # j
- Start **step** # k

- Stop **step** # k
- Stop **track** # j
- Stop event # i
- Stop run # 1



k Track ID

Track stack

active

waiting

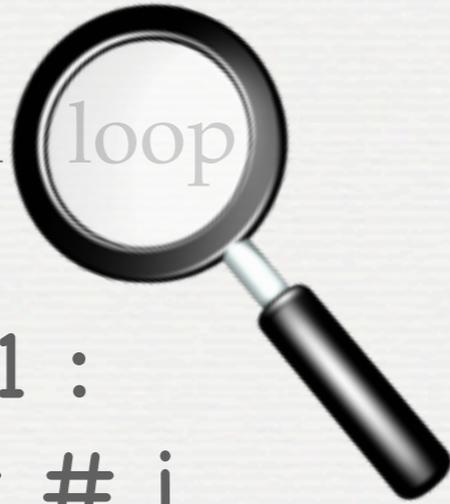


What is It?

ALL G4Things together

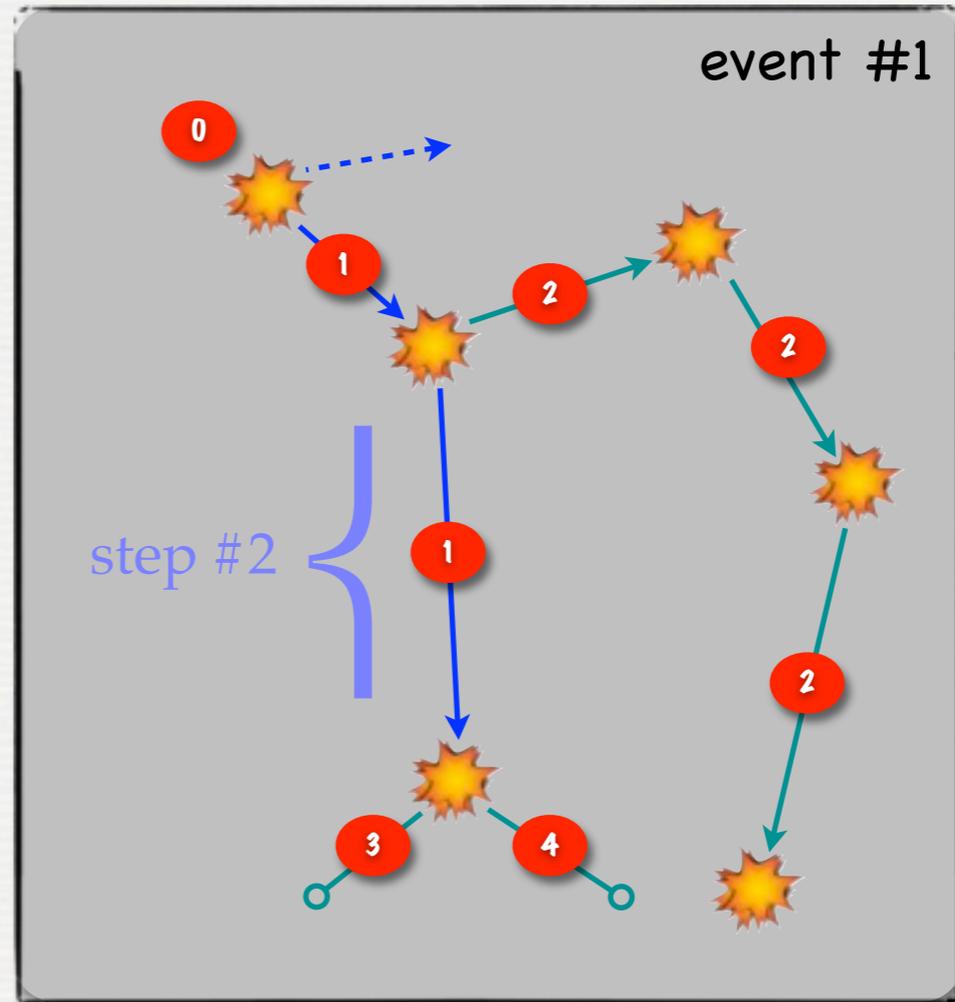


'Loupe' on the main loop



- Start run # 1 :
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- Start **step** # k

- Stop **step** # k
- Stop **track** # j
- Stop event # i
- Stop run # 1

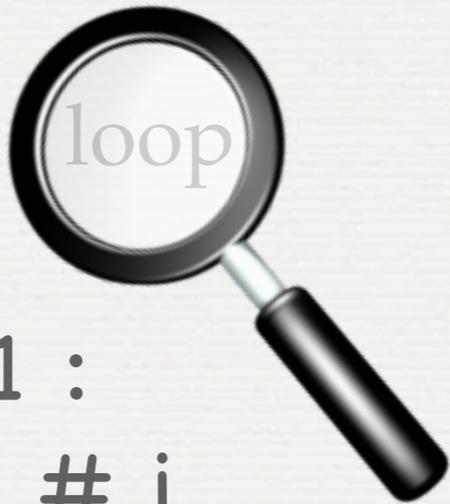


What is It?

ALL G4Things together

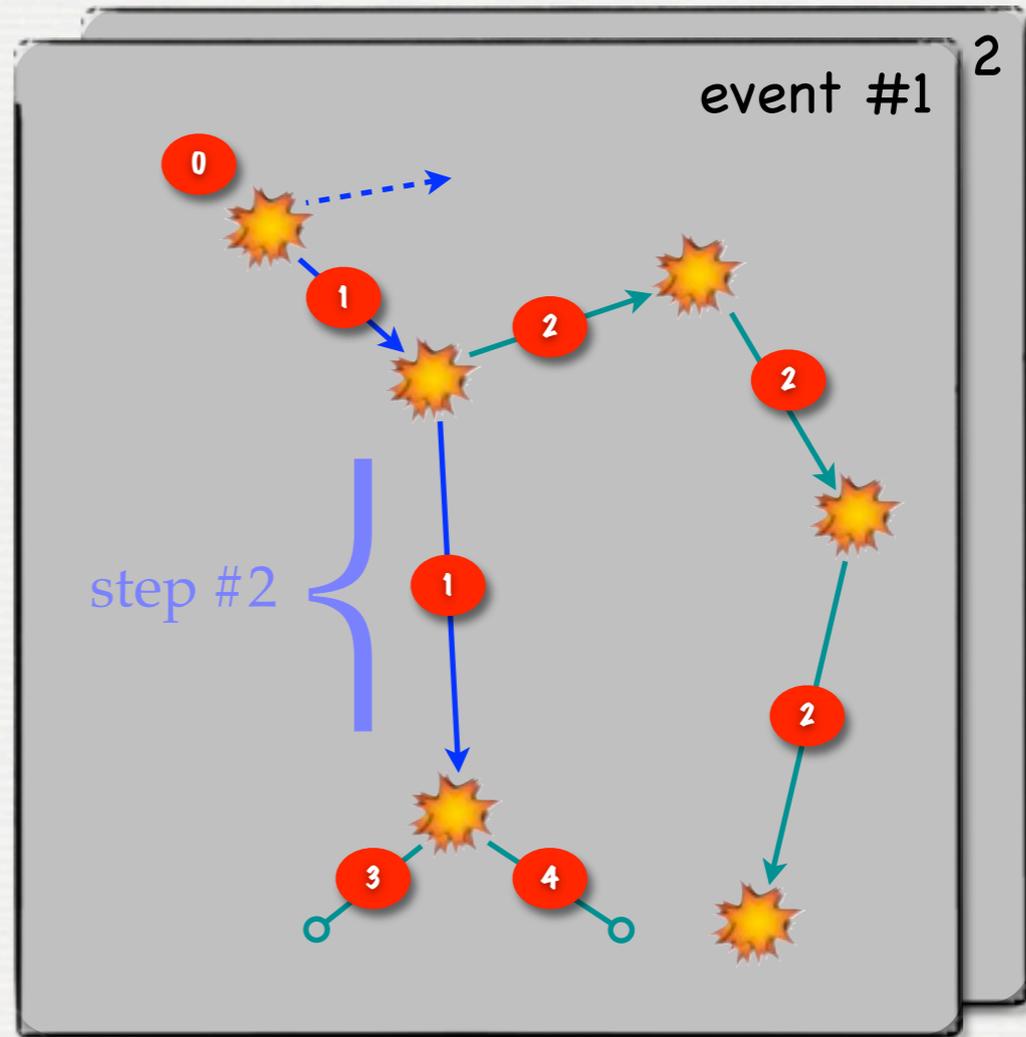


'Loupe' on the main loop



- Start run # 1 :
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- Start step # k

- Stop step # k
- Stop track # j
- Stop event # i
- Stop run # 1



k Track ID

Track stack

active

waiting

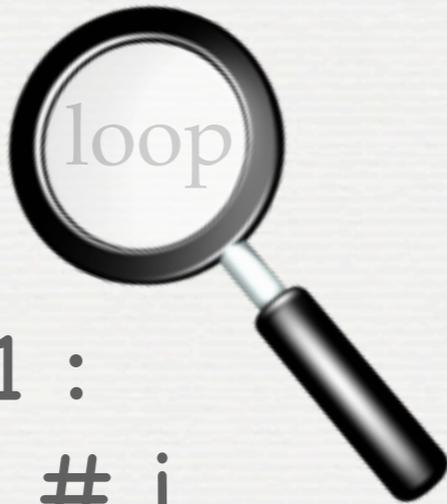


What is It?

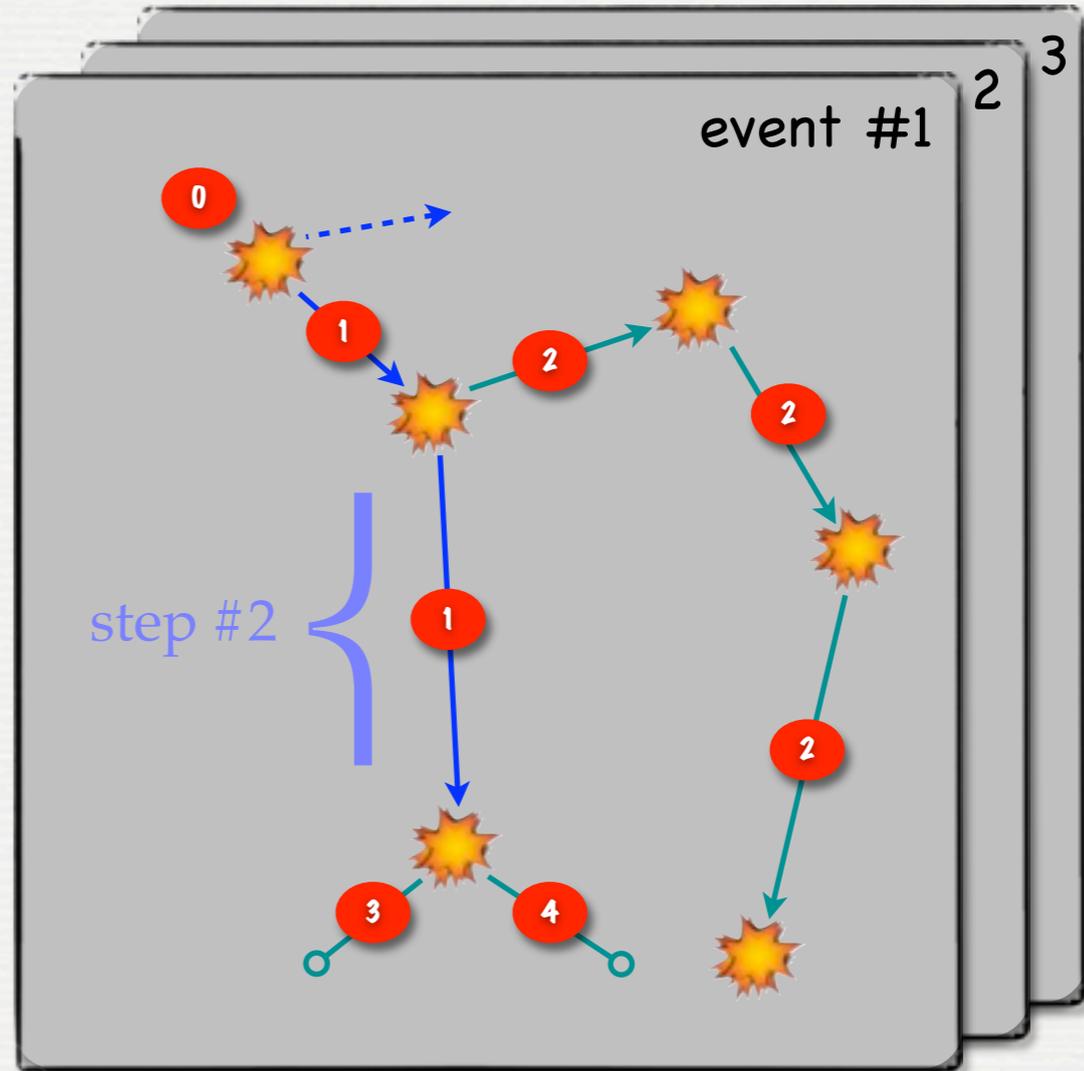
ALL G4Things together



'Loupe' on the main loop



- Start run # 1 :
- Start event # i
- Start **track** # j
- Start **step** # k
- Stop **step** # k
- Stop **track** # j
- Stop event # i
- Stop run # 1



k Track ID

Track stack

active

waiting



What is It?

ALL G4Things together



'Loupe' on the main loop



Start run # 1 :

Start event # i

Start track # j

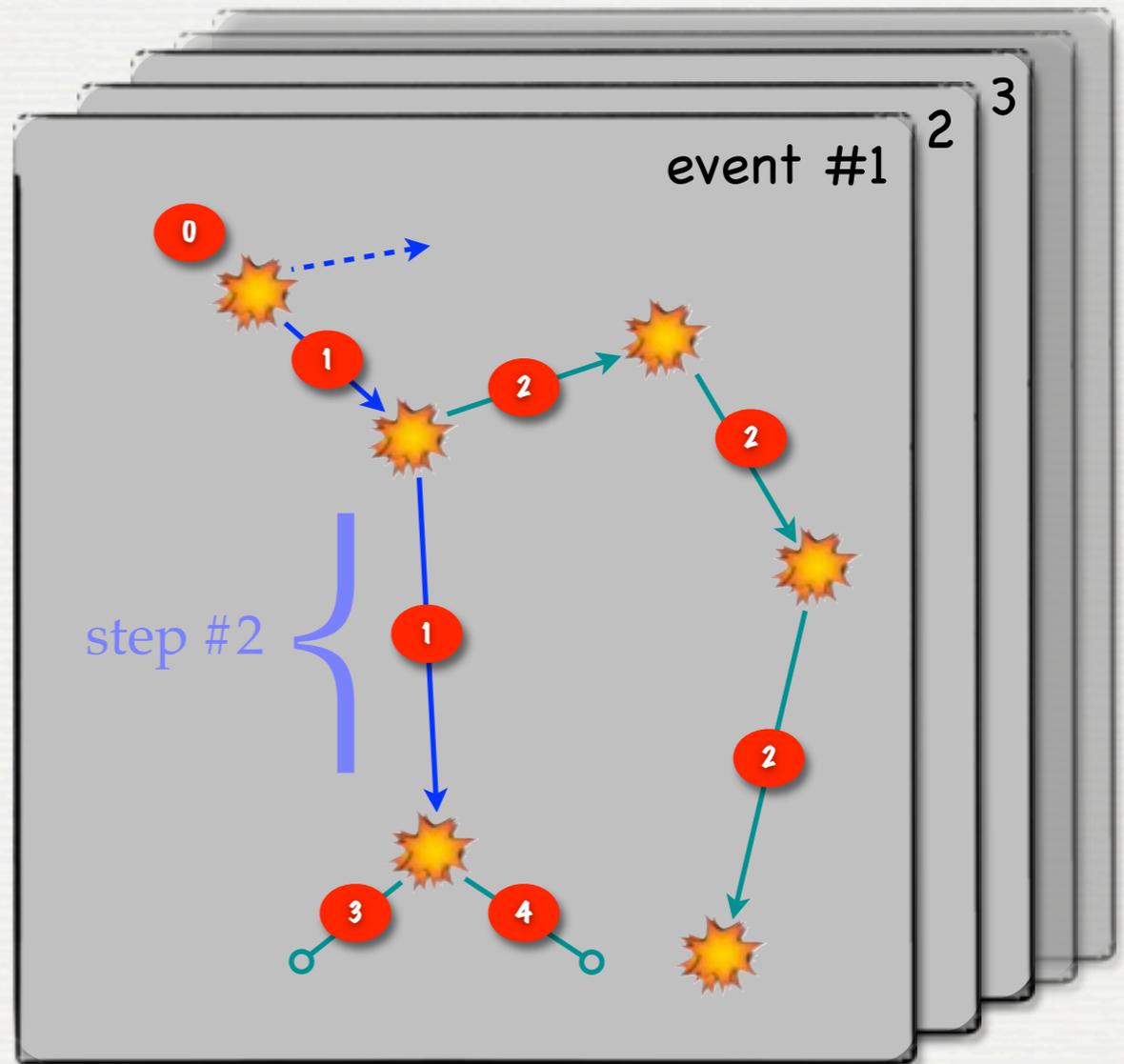
Start step # k

Stop step # k

Stop track # j

Stop event # i

Stop run # 1



k Track ID

Track stack

active

waiting

What is It?

ALL G4 Things together



'Loupe' on the main loop



Start run # 1 :

Start event # i

Start track # j

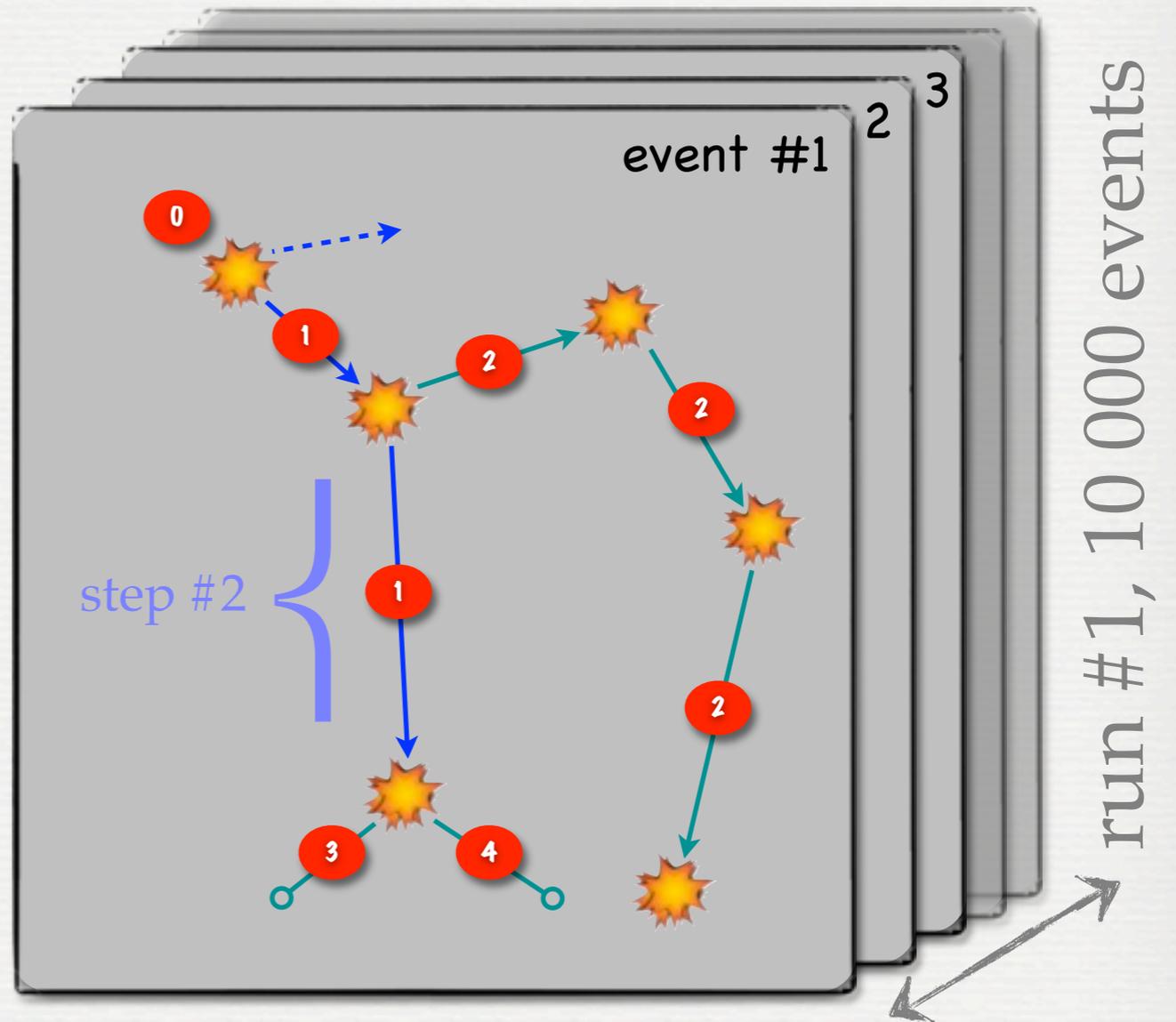
Start step # k

Stop step # k

Stop track # j

Stop event # i

Stop run # 1



k Track ID

Track stack

active

waiting

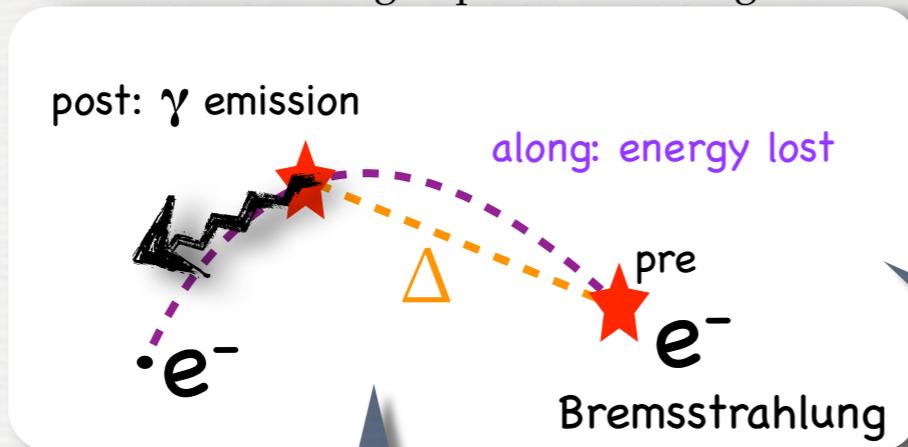
What is It?

Some remarks about steps



★ G4Step do not match necessarily the real trajectory

same remark for charged particles in magnetic fields



★ G4StepPoint: one Pre, one Post

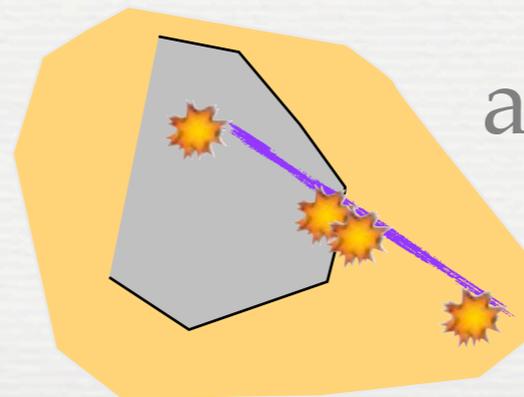
△ G4Step: store delta information

once a process is selected:

- 1 all AlongStep are applied
- 2 PostStep of the selected

in G4, distinctions between:
Along, PostStep, AtRest
processes

★ Fictive G4Step introduced



at boundaries

What is It?

Some remarks about steps



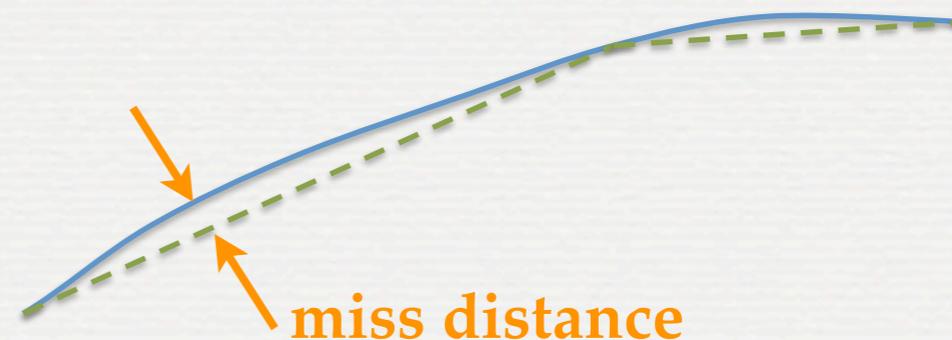
- ★ In order to propagate a **particle inside a magnetic and/or electric field**, the equation of motion of the particle in the field is solved
- ★ The *Runge-Kutta* method for the integration of the ordinary differential equations of motion

- ★ In specific cases other solvers can also be used:

In a uniform field, using the analytical solution

In a nearly uniform field (BgsTransportation)

In a smooth but varying field, with new RK+helix



- ★ Knowing the **trajectory**, G4 breaks up this curved path into **linear chord segments**

➔ The chord segments are chosen so that they closely approximate the curved path

➔ The chords are used to interrogate the Navigator, to see whether the track has crossed a volume boundary

➔ The accuracy is controlled using a parameter called the '**miss distance**':

it is a **measure of the error** in whether **the approximate track intersects a volume**

default 3mm

to be adapted for your physics ...

What is It?

Some remarks about steps



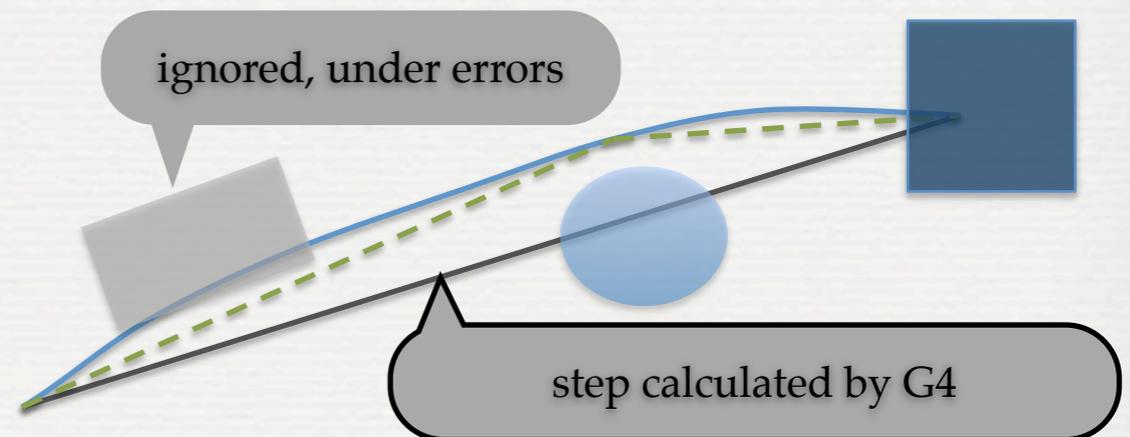
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- ★ The *Runge-Kutta* method for the integration of the ordinary differential equations of motion.

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What is It?

Some remarks about steps



Geant4 introduces 'cuts'

- To avoid infrared divergence for electromagnetic processes
 - ▶ for gammas, electrons and positrons
- It is a distance (1.0 mm) converted to energy for each material
- It is not a tracking cut (i.e. stop tracking if step < 1.0mm)
 - ▶ Geant4 tracks particle down to zero kinetic energy
- It is a energy threshold*
 - ▶ above: secondaries created
 - ▶ below: just energy loss
- It could be a global, per particle or per region parameter

*at which discrete energy loss is replaced by continuous loss ... up to zero ...

Conclusions / remarks

Why? because it helps a lot !

A C++ toolkit, based on Monte Carlo method to simulate particles interactions with matter

What is It?

Second time this lecture is given

↳ feedbacks mandatory !

Geant4 version 10.0 is also there

↳ running several CPU/cores in //

↳ more tricky to handle ...



The roadmap of the week

W1: installation / running a G4 application

W2: Primary generator, GPS, physics list

W3: Geometries !

W4: Sensitive detectors / user's actions

w1: 3:00, Wednesday
w2: 3:00, Wednesday
w3: 4:30, Thursday
w4: 3:00, Saturday

NOW, HOW does it really work ?